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DEVELOPMENT OF A FLIGHT SIMULATOR AND AN INTELLIGENT SYMBOLOGY MANAGEMENT SYSTEM FOR HELMET MOUNTED DISPLAYS IN ROTORCRAFT

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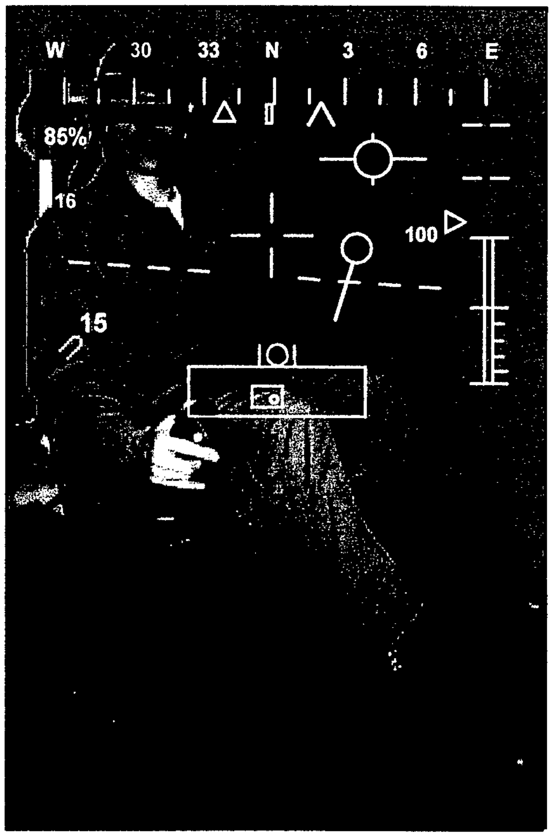

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The overall objective of this project was to develop and evaluate an innovative and intelligent information presentation system for helmet-mounted displays (HMDs) in military helicopters. The subordinate objectives included: (a) defining specific information elements that should be presented via the HMD, (b) developing a powerful, portable, flight simulator to permit rapid identification and evaluation of candidate symbols and their management, and © developing and testing innovative flight and mission information symbology management concepts, realistically demonstrating the most promising candidates on the portable simulator.

The report describes the symbology management issues of mode switching and information organization and the heavy burden of Army mission management tasks, and presents HMD solutions to the current shortcomings, focusing on "augmented reality" as the key to workload reduction and situation awareness enhancement. The report also describes the design and development of the PRISMS virtual reality flight simulator, and how it was used to conduct a formal experiment with 14 Apache pilots. The experiment demonstrated the overwhelming advantages of new earth-fixed HMD symbols such as waypoint and engagement area markers. A wealth of pilot comments and subjective ratings on these and other symbols and their intelligent management is also presented.

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Acknowledgments

It was evident that if we were to meet our objective of development of an intelligent symbology management system for HMDs in rotorcraft, in-depth interviews would be needed with the only true subject matter experts (SMEs), the Apache pilots themselves.

The authors are very grateful to these pilots for their perceptive and judicious responses to our knowledge-acquisition techniques, and for their carefully-considered suggestions for applying new technology to meet Army operational requirements.

The initial interviews and simulator flights were provided by E. Mike Couch, an aviation simulator specialist and an AH-64 SME employed by Anacapa Sciences. Mr. Couch's instructions, insights, and demonstrations were instrumental in focusing our interview materials on high-payoff topics.

Project Phase I Pilots

D Company, 1/14, Aviation Training Brigade. Fort Rucker, Alabama

CW3 Brett J. Armstrong
CW2 Olin R. Ashworth
CW3 Scott A. Beiler
CW2 Richard D. Bewley
CW2 Wayne E. Gore
CW2 Edmond E. Hallmark
CW2 Craig R. Mowitz
CW2 Mike Reese
CW3 Duane Stanislaw
CW3 Dale Stroud
CW2 Michael S. Wells
CPT Jan W. Westerbeek

Project Phase II Pilots

1st Battalion (Attack), 211th Aviation Regiment, West Jordan, Utah

Lt.Col. Michael Jensen
Maj. Bart Berry
Maj. Rodney Robinson
Cpt. Gordon Behunin
Cpt. Nick Pino
CW4 Daniel Lindberg
CW4 Gary Wallin
CW3 Theodore Cotro-Manes
CW3 Clifford Cox
CW3 Ken Jones
CW3 Steve Rugg
CW3 Fabian Salazar
CW3 Russell Thacker
CW2 Will Gummersall
CW2 Corbet Oxborrow

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- S. P. R.
- C. N. A.

Executive Summary

This Final Technical Report is submitted in accordance with the provisions of Contract No. DAAJ02-96-C-0042, issued by the Aviation Applied Technology Directorate, U.S. Army Aviation and Troop Command, Fort Eustis, VA. The report describes a project supported by a Small Business Innovation Research (SBIR) Program Phase II contract (Topic OSD 95-002I). The project has been conducted to explore the development of an intelligent symbology management system for helmet-mounted displays in rotorcraft.

The overall objective of this project was to develop and evaluate an innovative and intelligent information presentation system for HMDs in military helicopters The subordinate objectives included the following:

(a) Define the specific information elements that should be presented via the HMD to support pilot tasks, especially as aircraft flight regimes and tactical requirements change during the course of a mission.

(b) Develop a powerful, portable, intelligent symbology management HMD simulator to permit rapid and effective identification and evaluation of candidate intelligent prioritization and filtering of flight mode information.

(c) Develop and test innovative flight and mission information symbology management concepts on the portable simulator, realistically demonstrating the most promising concepts for providing timely information to the pilot.

Section 1 provides an overview of the background and general approach taken in performing this project and describes the need for a sophisticated, low-cost HMD research simulator. Section 2 describes the activities undertaken during the Phase I SBIR effort, including the initial information requirements analyses and preliminary interviews with Apache subject-matter experts.

Section 3 examines the symbology management issues of mode switching and information organization, contrasting the current pilot-operated mode switching methods with alternate psychomotor controls and comparing the symbology moding strategies of the AH-64 Apache, RAH-66 Comanche, and the ANVIS/HUD.

Section 4 describes the heavy burden of Army mission management and communication tasks and describes HMD solutions to the current shortcomings, focusing on the concept of "augmented reality" as the key to workload reduction and situation awareness enhancement. This section also describes the mission information requirements analysis and the 124 information elements identified as potentially useful on an HMD display.

Section 5 describes the design and development of the PRISMS virtual reality flight simulator, including the research requirements for such a device, the physical configuration of pilot and experimenter stations, control devices, HMD, head-

tracker, flight model, digital terrain data, sound and video systems, data recording capabilities, and user interface.

Section 6 discusses the formal experiment carried out with 14 Apache pilots at the 211th Aviation Regiment at West Jordan, Utah, exploring new earth-fixed symbols for indicating tactical positions critical to Army rotorcraft missions. The experiment was most effective in demonstrating the overwhelming advantages of the new earth-fixed symbol types. The accuracy of position-finding in the terrain and engagement area fire sector identification were enormously improved through the display of virtual waypoint and engagement area symbols.

Section 7 presents the results of the knowledge acquisition sessions conducted with the Apache pilots immediately following the experiments. Several new HMD symbols were demonstrated and evaluated by the pilots, including new symbols for presenting slope landing data, wind speed and direction, required speed for accurate arrival time, threat weapon direction, and flight path prediction. All of these new symbols were judged to be quite valuable, especially if intelligently moded. The pilots suggestions for intelligent moding opportunities are also described. The section concludes with the results of a survey rating the importance of information elements potentially displayable as HMD symbols, as a guide for prioritizing future research.

In addition, the project has also demonstrated the relative ease with which the PRISMS simulator can be used to construct and edit experimental sessions, add and improve symbology features and behaviors, provide realistic terrain and objects, and create an extensive range of performance measures—all in a package that is easily transportable to the field. PRISMS has not only fulfilled its project objectives, but will continue to provide a powerful but inexpensive simulator for research and training for many years to come.

Contents

Contents (Continued)

Contents (Continued)

Contents (Continued)

List of Figures

List of Figures (Continued)

Figure **Page**

List of Figures (Continued)

List of Tables

Section 1: Introduction and Project Summary

This Final Technical Report is submitted in accordance with the provisions of Contract No. DAAJ02-96-C-0042, issued by the Aviation Applied Technology Directorate, U.S. Army Aviation and Troop Command, Fort Eustis, VA. The report describes a project supported by a Small Business Innovation Research (SBIR) Program Phase II contract. The project has been conducted to explore the development of an intelligent symbology management system for helmet-mounted displays in rotorcraft (SBIR Topic OSD 95-002, Phase II).

Background

Military helicopter pilots experience high workload demands as a normal condition of combined aviation, navigation, communication and mission management requirements. Missions performed by nap-of-the-earth (NOE) flight in threat areas at night or in adverse weather conditions are extremely demanding upon all of the pilot's perceptual, cognitive, and psychomotor resources. Although there is a broad awareness of these problems, the continuing addition of new avionics capabilities is potentially leading to ever-greater, rather than reduced, workloads.

In particular, the development of avionics for presentation of symbology on a helmet-mounted display (HMD) will greatly increase the pilot's information management requirements. New symbols for flight control, sensor systems, weapons management, target acquisition, navigation, data linking, aircraft survival equipment, and battlefield awareness aids are all competing for space on the HMD. The HMD, originally developed to reduce workload and permit pilots to keep their heads up and eyes out of the cockpit, could potentially be cluttered with symbology that obscures the real-world terrain. As a result, the management of HMD symbology could rapidly becoming a high-workload task in itself.

AH-64 Apache HMD

Currently, the only U.S. production aircraft that makes use of an HMD and a flight symbology graphics generator is the AH-64 Apache helicopter. The Apache Pilot Night Vision System (PNVS) provides a head-steered Infrared (IR) image overlaid with flight symbology to the pilot using a monocular HMD designated as the Integrated Helmet and Display Sighting System (IHADSS), as shown in Figure 1-1. Although the IR image is head-steered, most of the flight symbology is independent of head position, and appears as if "painted" on the HMD screen. Thus, the IHADSS is comparable to a miniature Head-Up-Display mounted on the helmet.

Figure 1-1. IHADSS helmet mounted display system.

Pilots have often noted that the symbology moding approach used in the AH-64 is less than ideal, both in terms of its specific organization of symbols, and in the manual mode switching actions required of the pilot. The IHADSS uses four moding options: Hover, Bob-up, Transition, and Cruise. The flight symbology mode switch, located on the cyclic handgrip, is a three-position momentary switch which permits the selection of the four different flight symbology modes.

Emphasis on the Pilot

The AH-64 is a tandem aircraft in which the pilot sits in back and the co-pilot gunner (CPG) occupies the front seat. Both pilots wear the IHADSS and have access to a number of common symbol elements. However, the pilot is the only one who views PNVS symbology as part of his aircraft controlling duties. The CPG is responsible for viewing terrain, navigating, and operating the aircraft's complex weapon systems (guns, rockets, missiles). In support of these duties, the CPG uses a different sensor system, the Target Acquisition Display System (TADS), and spends a good portion of each mission head down, with the IHADSS monocle pulled back. Consequently, his present use of IHADSS symbology is limited, and his requirements are quite different from those of the pilot. In order to focus our planned development of an intelligent management system on the heaviest user of HMD symbology, we confined our investigations to establishing the *pilot's* requirements for improved moding and

symbology presentation methods on the IHADSS. However, many of the recommendations and conclusions of our study will apply equally to the CPG.

Anacapa Sciences' Philosophy of Symbology Research

The Difficulties of Display Design

There is broad agreement in the avionics design community that HMD symbology development issues are very complex because of the many different kinds of requirements involved. Operational requirements determine the information that must be presented to the pilot; technological advances impact the potential range of presentation methods; human perceptual and cognitive capabilities and limitations constrain symbol characteristics; and the history of avionics development has imposed a number of standards, methods, and expectations on the design process itself.

Given the multidisciplinary character of the design requirements, it is logical to assume that similarly constructed teams might offer the best approach for addressing the problems of symbology development. Unfortunately, there is no set of guidelines readily available to assist the multidisciplinary design team in the selection of the optimal information presentation methods, nor is there even a commonly-accepted model of symbology development. For example, Newman & Haworth (1994) in discussing shortcomings of HMD symbology state that "The underlying causes are (1) the absence of a logical, organized design methodology and (2) the absence of a test and evaluation criteria." In addition, Weintraub & Ensing (1992), in their review of head-up display issues, note regretfully that "Improved symbology solutions cannot now be designed and constructed from theory, or from a set of design principles. Present symbology design seems to be partly science, partly technology, and partly cut and try."

As a result, the design process often seems more of an institutionalized struggle among groups having very different objectives than the goal-oriented interactions of a design "team." Salter (1991), for example, describes the fundamental nature of the interface design task as "better conceived of as the reconciliation of conflicting constraints than as the application of clear-cut rules." Not surprisingly, the absence of a clear model for the symbology design process is closely related to the lack of agreement on the definition of a broadly accepted HMD symbology set. The true benefit of a clearly articulated, top-down symbology design process lies in the subsequent phases of display design, in which complexity can be systematically managed; the products of thinking can be readily understood, evaluated, and modified; and gaps in knowledge made evident. It is in the light of this philosophy that our model of the symbology development process was constructed.

The Symbology Development Model

Over the past several years of research in the area of symbology development, we have developed a conceptual model of critical issues that must be addressed, and their hierarchical relationships (e.g., Rogers & Spiker, 1995). This model is shown in

simplified form in Figure 1-2, below. Although the actual process is vastly more complex than that shown in this diagram, depicting the relationships among the major issues nevertheless provides a very useful structure for organizing the available knowledge on symbology development.

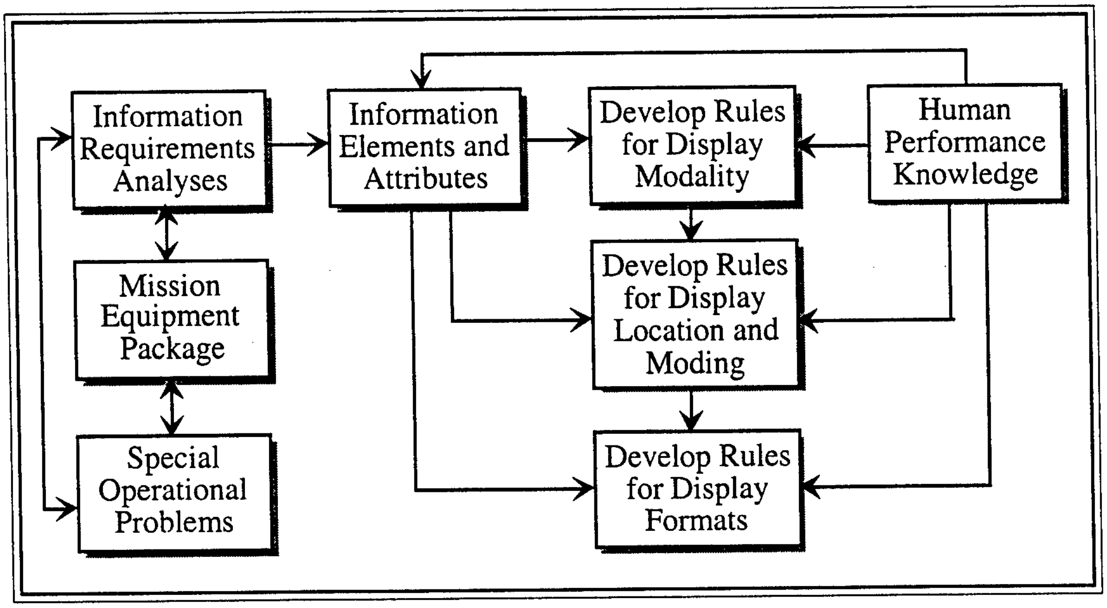


Figure 1-2. The symbology development model, in simplified form.

The diagram shows a logical sequence of issues to be addressed, yet it is not anticipated that these events will actually follow in a smooth chronological order; continuous iteration is to be expected, and desired. Nevertheless, conceptualizing the process in this manner is quite helpful in recognizing the utility and role of new information as it becomes available, and in anticipating the potential benefits of this information for "downstream" activities. The focus of the Phase II research was on the box entitled "Develop Rules for Display Location and Moding," serving to underscore that the research must thus address all of the "upstream" activities. Our methods for addressing each of these activities is described below and in the following section of the report.

Figure 1-2 also shows that the development of symbology systems is responsive to two major influences: the information to be conveyed, shown at the left of the figure, and the current knowledge regarding human performance with display techniques, shown at the right of the figure. The information requirements must be determined by analytical methods, and are influenced by the mission of the aircraft, special operational problems experienced by the pilot, and the particular set of equipment to be used in performing the mission and meeting the special problems. These analyses identify the specific information elements that must be presented to the pilot, and the attributes of this information, such as "spatial" or "numeric."

The human performance knowledge includes principles from studies of human perception and cognition, aviation design standards, "lessons learned" from flight tests, and guidelines from human factors engineering and related disciplines. The nature of

the human performance knowledge influences the information requirements analyses as well as the development of the display rules by identifying elements and attributes of potential design importance based on human information processing capabilities and limitations.

Need for Multiple Approaches

For many years, Anacapa has performed a variety of research studies of avionics symbology development for fixed wing and rotary wing aircraft. Based on our experiences, we have come to believe that there is no single "true path" to display and symbology improvement, and that any single approach is almost certainly doomed to producing minor symbology improvements, if not outright failure. It is imperative that parallel methodological paths be followed to include the knowledge that can be gleaned from different fields of expertise and forms of evaluation. As shown in Figure 1-3 the knowledge from three communities must be acquired and integrated in the design process. In addition, a variety of tools must be brought to bear that effectively integrates the information from these communities.

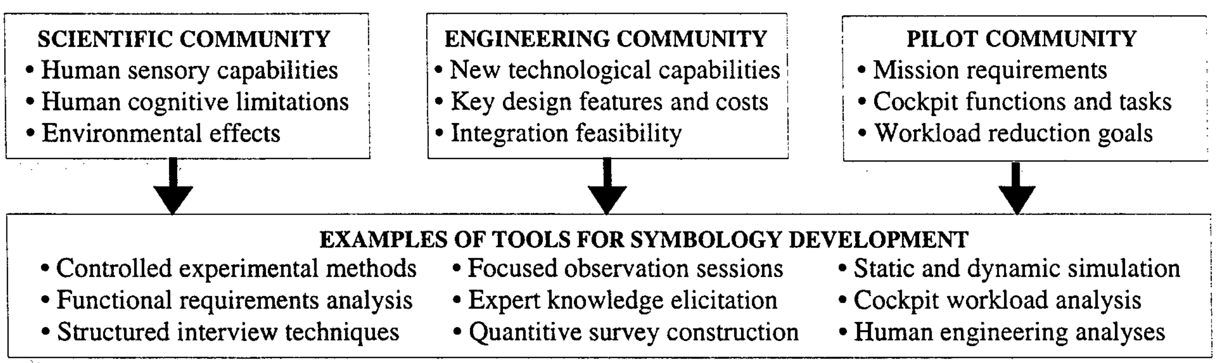


Figure 1-3. Examples of the range of expertise and methods required for good symbology design.

Symbology development requires information from the scientific, engineering, and pilot communities. Each of the communities offers important knowledge, yet each has its limitations if used without supporting data from other sources of data and insight. For example, new technological capabilities, while impressive, may offer nothing to improve a pilot's performance, and may even increase his workload. Vision or cognition research may be inapplicable if it does not fully consider limitations to display system capabilities or the actual nature of the operational tasks performed. The pilot's absorption with expertise in certain tasks may become irrelevant with new, intelligent, avionics systems.

In like fashion, the tools themselves have advantages and disadvantages. Controlled experiments are powerful stimulators of information and insight, but the utility of their results depends upon having selected variables that reflect an understanding of the pilot's functions and tasks. Expert knowledge elicitation, in isolation, cannot serve to develop new, better techniques for display of integrated information. Task-analytic methods are necessary for organization of knowledge, but

do not lead to creative solutions. In short, we believe that symbology development and intelligent symbology management research requires the flexible and creative application of a broad array of techniques, and that a clear, direct path to innovative solutions cannot be completely planned in advance.

Need for a Sophisticated, Low-Cost HMD Research Simulator

It became evident that one necessary step along the path was the development of an HMD research simulator that could be used to aid in integrating the knowledge from the three communities, demonstrating established problems and their candidate solutions, and applying the range of research tools in the most meaningful ways. On one hand, we had to acknowledge that a number of research helicopter simulators already existed and, like the Crew Station R&D Facility (CSRDF) at NASA Ames Research Center and the Simulator Training Research Advanced Testbed for Aviation (STRATA) at the Army Aviation Center, have served as testbeds for valuable studies in recent years.

The use of such powerful simulators, however, has been accompanied by certain disadvantages. In general, they are extremely expensive to construct, require specialized technical support personnel, are time-consuming to reprogram for new applications, and are certainly not portable to other locations. These simulators are also in great demand for major research projects, such as the LHX studies of past years at the CSRDF and the Air Warrior research now underway at the STRATA facility. Despite the surge of interest in HMD display systems, it is difficult for small research groups to obtain access to these costly and tightly scheduled simulators.

We believed that the solution to these problems was in the development of a sophisticated, but relatively low-cost HMD research simulator. Not only would such a device permit HMD simulator access to more research agencies, but if properly designed, would provide a number of additional advantages. We planned to develop a low-cost HMD research simulator to provide the capabilities necessary to show HMD symbology in screen-fixed, aircraft-fixed, and earth-fixed frames of reference, along with a gaming area of realistic terrain and facilities for demonstration, knowledge acquisition, experimental control, and data recording.

It seemed clear that an immersive approach with an opaque visor could be used, saving costs, yet providing an effective virtual reality experience. It could be paired with an accurate head tracker so that symbology would be positioned and made to behave appropriately based on the user's head movements. Such a system could be configured to simulate flight through terrain generated from digital terrain elevation data (DTED). It could also employ some representative versions of helicopter cyclic and collective controls, and a capability of realistic flight through the terrain for demonstrations, experiments and training purposes.

Furthermore, we believed that it could be designed for flexible use so that individual scientists would find it easy to incorporate and demonstrate symbology ideas, easy to program for experiments, and easy to transport to meetings, military facilities, and other sites for clear communication of symbology behavior and knowledge

acquisition sessions. In short, we were certain that a low-cost HMD research simulator could be constructed to serve us well in conducting the Phase II effort as well as in providing an innovative product that could be used by scores of research and training organizations unable to afford multi-million dollar simulators.

Objectives of the Phase II Research Effort

The overall objective of the Phase II effort, was to develop and evaluate an innovative and intelligent information presentation system for an HMD in a synthetic environment. The subordinate objectives, based upon our philosophy of symbology system design, included the following:

(a) Define the specific information elements that should be presented via the HMD to support pilot tasks, especially as aircraft flight regimes and tactical requirements change during the course of a mission.

(b) Develop a powerful, portable, intelligent symbology management HMD simulator to permit rapid and effective identification and evaluation of candidate intelligent prioritization and filtering of flight mode information.

(c) Develop and test innovative flight and mission information symbology management concepts on the portable simulator, realistically demonstrating the most promising concepts for providing timely information to the pilot.

Underlying goal of broad and continuing applicability. In addition to the specific objectives stated above, we believed that an underlying goal of the project was that the "innovative intelligent symbology management system" must be applicable beyond any one specific aircraft. Thus, although we had chosen to focus on the characteristics of the AH-64 aircraft because of the availability of SMEs, the products of this Phase II effort were most definitely to extend beyond the AH-64 aircraft and equipment. The extended applicability of this work was to take two different forms: first, the broad relevance of research results and second, the continuing value of the research methodology:

(1) *Broad relevance of research results.* The results themselves were to offer not only specific HMD symbology solutions for the AH-64, but include broadly generalizable concepts that would be applicable to a range of current and future aircraft. For example, although a new type of warning symbol might be designed to appear in somewhat different colors, shapes, or locations in various aircraft, the recognition that the information element is critical and that certain events can be sensed to permit its automatic presentation should be useful in multiple aircraft types.

(2) *Continuing value of the research methodology.* Because the information content of the HMD will vary enormously given the different aircraft mission equipment packages, or MEPs (i.e., sensors, weapons, target acquisition methods, navigation systems, communication systems, aircraft survival equipment, and battlefield awareness aids), no single set of intelligent symbology management techniques can be expected to fully meet the requirements of new systems. For this reason, a portion of our Phase II effort was to be devoted to devising an efficient methodology for iden-

tifying and evaluating intelligent symbology management opportunities as they arise from the addition of new aircraft to the field, or new equipment items to existing aircraft.

Overview of the Phase II Technical Approach

The overall approach to the Phase II effort is shown in Figure 1-4, below. In Task 1, based on our successes in the Phase I effort, we continued and greatly broadened our efforts in identifying innovative symbology management concepts. In Task 2 we expanded our analyses of mission information requirements to include a much larger array of pilot functions and tasks than had been addressed during Phase I. The products of Task 1 and 2 supported Task 3, a concurrent, parallel effort to develop a relatively low-cost, but sophisticated intelligent symbology simulator, incorporating an immersive HMD and head-tracker system with multiple frames of reference for symbology presentation.

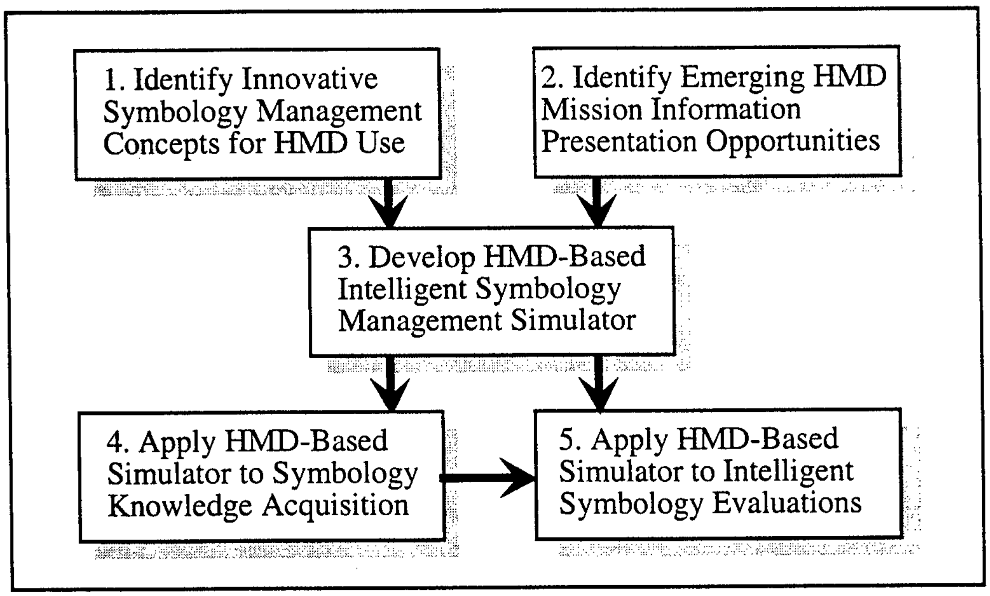


Figure 1-4. A diagram of the five tasks in the Phase II project.

Our new Pilot-Rotorcraft Intelligent Symbology Management Simulator (PRISMS) was designed to present rapidly reconfigurable screen-fixed, aircraft-fixed, and earth-fixed symbology in a variety of mission scenarios. Thus, the complexities of symbol motion dynamics are realistically presented to the SMEs and their ideas can be incorporated for "quick-look" evaluations. The simulator software was designed to be capable of direct use in helicopter flight tests as well. Tasks 1, 2, and 3 supported Task 4, the application of the HMD-based simulator to knowledge acquisition sessions with SME pilots. Because the simulator is portable, we were able to transport it to a suitable Army site for experimental and knowledge acquisitions sessions with Apache pilots.

In addition to its symbology presentation capabilities, the PRISMS simulator was specifically designed to manage controlled experiments, recording such data as RMS error in altitude, airspeed, and flight path, as well as response times for target or event

detection. These capabilities, and many more, were put to use in the ground-based intelligent symbology management evaluations of Task 5. Experiments conducted during Task 5 were used to identify the most promising configuration of intelligent symbology management characteristics and to explore the effectiveness of various moding rules employed to control the presentation and behavior of the new symbols.

Loss of Flight Testing Activities in the Phase II Project

The original description of the Army SBIR Topic OSD95-002, called for preliminary evaluations of intelligent information presentation concepts for an HMD to be performed in "both ground and *in-flight simulation* to verify improvement potential. Complete definition of intelligent symbology management characteristics of the most promising configuration will be *verified in flight tests on helicopters with HMD systems*" (italics added).

We were pleased to see in-flight testing called out as a research requirement; in our view, there is no symbology evaluation methodology that is more convincing than the measurement of aviators' performance in flight, provided that the previous steps in the symbology design process have been effectively carried out. We were particularly eager to validate our intelligently-moded symbology using the FLITE (Flying Laboratory for Integrated Test and Evaluation) aircraft as Government-Furnished Equipment (GFE).

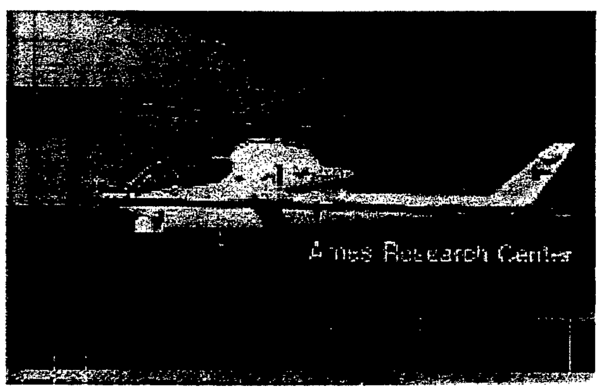


Figure 1-5. The Flying Laboratory for Integrated Test and Evaluation.

Unfortunately, due to Army operational requirements, FLITE became unavailable during the project's period of performance. Instead, all tests were to be performed using our PRISMS simulator. Although disappointing, this change had less practical effects than it might seem. All of the symbology testing we had envisioned for FLITE could easily be performed on the PRISMS simulator.

Organization of the Report

The remainder of this report is subdivided into six major sections. Section 2 describes the activities undertaken during the Phase I SBIR effort, including the initial information requirements analyses, preliminary interviews with Apache subject-matter experts, flights in the Army's STRATA simulator, the development of an animated

laptop symbology simulator, and the results of interviews and a survey of instructor pilots at the Army Aviation Center at Fort Rucker, Alabama.

Section 3 describes the conduct and results of Task 1, examining the symbology management issues of mode switching and information organization. The current pilot-operated mode switching methods are contrasted with alternate psychomotor controls such as head- and eye-aimed controls, voice-actuated controls, touch-sensitive panels, and virtual hand controllers. This section also compares the symbology moding strategies of the AH-64 Apache, RAH-66 Comanche, and the ANVIS/HUD night vision system and describes the potential reductions in pilot workload with the development of an intelligent system to control the presentations of individual symbols.

Section 4 identifies the nature of Army mission management and communication tasks, showing the tremendous information-handling burden carried by the Army aviator and describes HMD solutions to the current shortcomings in mission management, focusing on the concept of "augmented reality" as the key to workload reduction and situation awareness enhancement. This section also describes Task 2, the mission information requirements analysis, the methods of identifying potential HMD symbology applications, and a list of 124 information elements identified as potentially useful on an HMD display.

Section 5 presents the design and development of the PRISMS simulator (Task 3) including the requirements for such a device, the desired capabilities, the physical configuration of pilot and experimenter stations, control devices, HMD, head-tracker, flight model, digital terrain data, sound and video systems, data recording capabilities, and user interface.

Section 6 discusses the formal experiment carried out with 14 Apache pilots at the 211th Aviation Regiment at West Jordan, Utah, exploring new earth-fixed symbols for waypoint markers, engagement areas, and other tactical positions critical to Army rotorcraft missions. The methods, procedures, experimental design, and results of the experiment are described in detail.

Section 7 describes the results of knowledge acquisition sessions conducted with the Apache pilots after demonstrations of several new HMD symbols were conducted immediately following the experiment. The section concludes with the results of a survey of the importance of information elements potentially displayable as HMD symbols.

Section 2: Review of Phase I Activities

The following pages describe our Phase I project activities, techniques, and outcomes. Although this section is not essential to the description of the Phase II project, this background information is offered here as a foundation for the tasks undertaken in Phase II.

The overall objective of the Phase I effort was to determine the feasibility of an innovative intelligent symbology management system for an Army Rotorcraft HMD. Subordinate objectives included:

(a) Determine elements of information necessary to support pilot tasks as aircraft flight regimes change during the course of a mission.

(b) Identify and evaluate innovative flight and mission information symbology management concepts, highlighting the most promising concepts for providing timely information to the pilot.

(c) Develop a portable, intelligent symbology management simulator to permit the comparison of candidate intelligent information prioritization/filtering techniques.

(d) Demonstrate potential increase in pilotage and mission effectiveness and the feasibility of the intelligent symbology management system concepts.

Having successfully concluded the Phase I effort, and with the luxury of hindsight, we believe these objectives to have been well-chosen. Not only were we able to attain these goals, but they had jointly led to a broader and deeper understanding of specific attack helicopter mission requirements and greater degree of insight regarding how these requirements can be supported through advanced HMD systems with intelligent symbology management.

During the initial months of our Phase I effort we primarily addressed the first two objectives. We identified the specific elements of information needed to support aviation and navigation tasks and determined how requirements for these information elements changes during the course of the mission. Because of the complex nature of the shifting requirements, we found it necessary to extend our analyses beyond flight control tasks in isolation, and begin to examine the tactical situations in which these tasks are performed. In addition, we identified several innovative flight and mission information symbology management concepts, and explored some promising concepts for displaying information to the pilot only when it is needed.

During the subsequent months of the Phase I effort, and armed with the information requirements and symbology management concepts, we turned to objectives (c) and (d). We focused on the development of a laptop HMD intelligent symbology simulator and definition of evaluation techniques for comparing baseline PNVS moding and intelligent symbology management approaches. Extensive

preparations were made for interviews with very experienced Instructor Pilots (IPs) at the Aviation Training Brigade at the Army Aviation Center at Fort Rucker, Alabama.

Research Conducted During Phase I

Information Requirements Analyses

We began the project by performing an information requirements analysis on a limited subset of mission functions to determine the specific elements of information necessary to support pilot tasks. The purposes of the analyses were to extract information directly pertaining to potential HMD intelligent symbology management characteristics, and were thus focused on issues perceived to be most likely to yield a payoff. The analyses were undertaken from two perspectives: AH-64-specific tasks and generic tasks. The advantage of studying AH-64-specific tasks was that workload metrics available to us could be used to identify demanding visual and cognitive tasks for discussing potential solutions with subject matter experts. The advantage of the generic-task approach was that it permitted the identification of potential symbology elements at an information level, rather than with reference to some existing piece of hardware in the AH-64A.

Examine Apache Workload Prediction Model Data

Anacapa has conducted a series of workload prediction studies for Army aircraft, including the Apache (e.g., Hamilton, 1992; Szabo & Bierbaum, 1986). The hundreds of tasks are described by verb-object pairs (such as "Check tailwheel switch") and by workload components ratings for visual, auditory, cognitive, and psychomotor task requirements made by Apache pilots. Examination of the detailed data has been useful in identifying tasks having high visual workload, such as: "set accelerometer," "check ACQ SEL switch," "check aircraft location," "check laser code," "set Doppler mode switch," "set gun burst limits," "set missile mode switch," "control rate of descent," "check standoff range," "enter target coordinates," "set transponder control switch," "set UHF frequency selector switches," and "set Mode 4 switch," among many others. Many of the tasks rated high for visual or cognitive workload led directly to fruitful discussion topics during the expert interviews.

Select Generic Flight and Mission-Oriented Segments and Functions

We then selected a set of in-flight activities to create a representative range of information elements and pilot information processing functions. The activities were selected to include events leading to changing symbology needs and were sufficiently demanding so that potential reductions in workload could ultimately be verifiable and valuable. In order to ensure that supporting subject matter experts would be available, the current AH-64 tasks served as the pool from which the analyzed activities were drawn. Nevertheless, the types of pilotage and mission functions examined were representative of those to be performed by aviators in the

foreseeable future, even in more advanced aircraft and using more powerful avionics capabilities, so that our findings could have long-term applicability.

Because Anacapa had previously developed detailed task and workload analyses in support of the AH-64 and Longbow aircraft, the basic structure of the tasks were familiar to us, saving extensive efforts in preparation for the information requirements analysis. In a recent top-down analysis (Hamilton, Rogers, & Spiker, 1995), we identified more than 200 functions for armed attack and reconnaissance mission. For the purposes of the Phase I effort, we selected a representative sample of about 25% of the relevant functions (based on HMD symbology impacts) and examined them in detail. The functions included all of the most applicable flight activities such as "perform rolling takeoff," "transition to hover," "transition to contour," "transition to NOE," "fly contour," "hover masked," and "fly IMC." In addition, we examined a sample of mission-oriented tasks such as "acquire ground target with helmet," "review threat hazards," "fire rockets," "fire guided missile," "assign fire zones to flight members," and "send situation report."

Study Results of Systematic Information Decomposition

A top-down analytical approach was used to establish the information requirements for the selected activities through systematic hierarchical decomposition of the representative mission segments (e.g., takeoff, NOE flight) into functions (e.g., mask aircraft, perform hover), tasks (e.g., control airspeed, select weapons system), requirements (e.g., Is the aircraft in trim?), and information elements (e.g., altitude, fuel quantity). Because of the limited time and resources of a Phase I effort, it was not possible to study every component of a mission, so we used interviews with subject matter experts (SMEs) to guide us to the high-payoff activities.

Descriptions of the required information elements were reviewed as a part of these analyses. Each element was described in terms of its units of measurement, current source, and other attributes. The units of measurement and source are important in determining how well or how easily this information can be sensed, not only by the pilot, but by an intelligent symbology management system. The attribute recording options were structured to help identify cues indicating that HMD display symbols should be presented on, or removed from, the HMD screen. For example, in the Comanche design, the attribute of "airspeed" is used to control the appearance of the flight path vector symbol.

Initial SME Interviews

The top-down analyses were supplemented by important bottom-up data on symbol requirements. Given that an AH-64 symbol set was already in existence, and familiar to hundreds of Army aviators, we elected to take advantage of this pool of SMEs to identify situations in which existing symbols are clearly required or not required for conduct of inflight tasks. These interviews focused both on individual symbols, as well as on the four display modes on the IHADSS: Hover, Transition, Cruise, and Bob-up. In the initial phase of interviewing (during October, 1995),

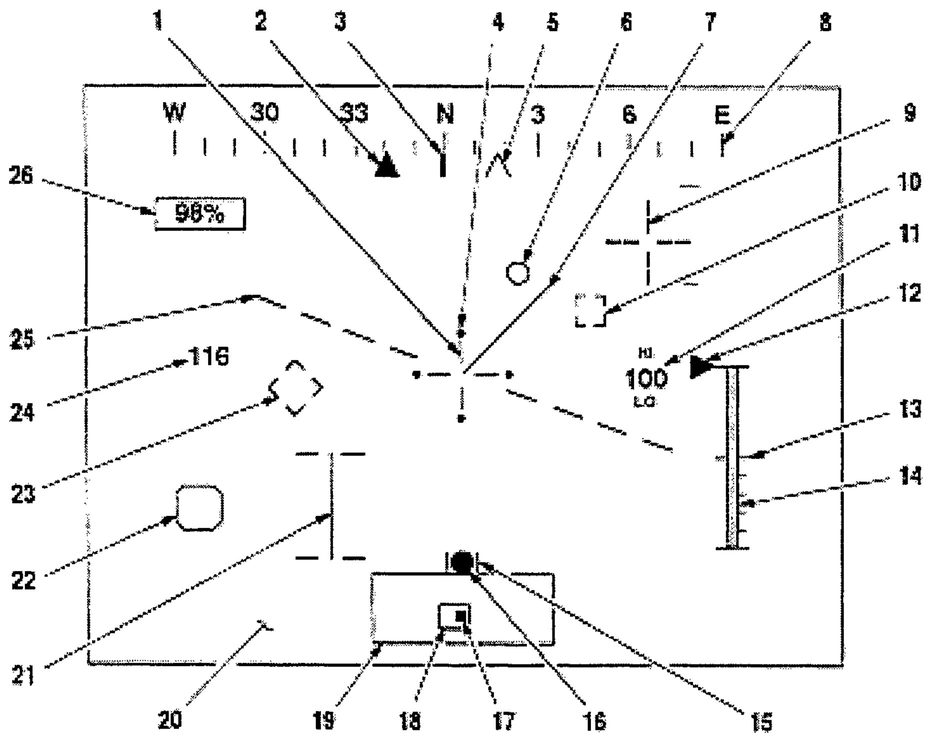
pilots on the Anacapa staff were queried, in order to develop an effective portable symbology simulator and design appropriate knowledge acquisition tools for use with the IPs.

A special interview booklet was prepared to summarize the available documentation on IHADSS symbology and guide the SMEs through the discussion of each symbol element. In order to clarify symbols interactions, the IHADSS symbols were discussed in terms of seven categories of information as shown in Table 2.1. The complete set of IHADSS symbols is shown in Figure 2-1, below.

Table 2.1
Organization of IHADSS Symbols by Information Category

Information Category	IHADSS Symbol
1. Position and Movement	Line of Sight (LOS) Reticle, Airspeed Digital Readout, Velocity Vector, Acceleration Cue, Hover Position Box, Radar Altitude Vertical Tape
2. Attitude/Altitude	Radar Altitude Vertical Scale, Radar Altitude Digital Readout, Horizon Line, Engine Torque Digital Readout, Rate of Climb Indicator, Skid/Slip Ball, Lubber Lines
3. Heading/Navigation	Heading Scale, Fixed Lubber Line, Command Heading, Alternate Sensor Bearing
4. Central Cueing/Reference	Head Tracker, Cueing Dots, Cued LOS Reticle
5. Peripheral Cueing/Reference	Field of Regard Box, Field of View Box, Cued LOS Dot
6. Weapons Usage	Rocket Steering Cursor, Missile Constraints Box
7. High-Action Display	Sight Status, Weapon Status, Weapon Control, Range/Range Source

Each IHADSS symbol was discussed in detail, confirming its format, typical location, and behavior. The specific purpose(s) of each symbol were confirmed, and the conditions under which each symbol appeared or disappeared were noted. Most of the symbols are always present, while others appear only in one of the four pilot-controlled modes (Cruise, Transition, Hover, or Bob-up). Still others appear or disappear according to special rules. For example, the Radar Altitude Vertical Tape disappears above 200 feet AGL, and reappears at 180 feet AGL. The characteristics of each symbol, i.e., its changes in content, form, or movement in correspondence with the underlying aircraft performance, was discussed in depth prior to scrutinizing its behavior in simulated flight. The findings are summarized in Appendix 1 (pages 75-102) of the Phase I report (Rogers, Spiker, & Asbury, 1996).



1. LOS Reticle
2. Alternate Sensor Bearing
3. Lubber Line
4. Cueing Dots
5. Command Heading
6. Acceleration Cue
7. Velocity Vector
8. Heading Scale
9. Cued LOS Reticle
10. Missile Constraints
11. Radar Altitude
12. Rate of Climb
13. Radar Altitude Scale
14. Radar Altitude Tape
15. Skid/Slip Lubber Lines
16. Skid/Slip Ball
17. Cued LOS Dot
18. Field of View
19. Sensor Field of Regard
20. High Action Display
21. Rocket Steering Cursor
22. Hover Position Box
23. Head Tracker
24. Airspeed

Figure 2-1. The IHADSS symbols shown in representative positions.

STRATA Simulator "Flights"

Preparation for the conduct of the SME interviews included use of the sophisticated STRATA simulator operated by the U.S. Army Research Institute Aviation R&D Activity (ARIARDA), at the U.S. Army Aviation Center at Fort Rucker, Alabama. When it was constructed in the mid 1980's, STRATA incorporated state-of-the-art technologies throughout the system, providing opportunities for innovative research in many areas. STRATA, designed as a reconfigurable research testbed, also provides all the necessary capabilities for an outstanding AH-64 simulator. Its technologies include the ESIG-1000 Image Generator (IG), capable of producing highly realistic out-the-window and sensor visuals; the Fiber-Optic Helmet-

Mounted Display (FOHMD), capable of presenting high-resolution, high-brightness images from the IG; and the Interactive Tactical Environment Management System (ITEMS), capable of accurately simulating the battlefield environment.

Figure 2-2. A view of the STRATA cockpit.

Given that our efforts were focused on the IHADSS and PNVS symbology issues, the STRATA capabilities were specifically configured so that the project Principal Investigator could experience the IHADSS display symbology under a variety of realistic visibility conditions, and during a range of flight and mission-oriented tasks.

To most effectively illustrate the behaviors of the symbols, the Principal Investigator was given an opportunity to "fly" the simulated AH-64 for several hours over the course of two days, performing Hover, Bob-up, Transition, and Cruise mode changes and other flight activities in rolling Arizona terrain, while closely observing the behavior of the PNVS symbology. The Apache SME in the other cockpit of the simulator clarified critical HMD symbology issues, suggested maneuvers for demonstrating symbol dynamics, and set up the systems for various tactical engagements. The flights included conditions of daylight, low light, low light overlaid with PNVS imagery, and night with PNVS imagery. The flights were alternated with interview sessions in order to most clearly illustrate the issues discussed during the interviews, identify situations in which various symbols were clearly required or not required during flight, and specify the key, potentially sensed events

(e.g., altitude, distance, time, location, or equipment use) that might serve as correlates of these changing information needs.

The Principal Investigator had been thoroughly familiarized with the IHADSS symbology by studying the AH-64 manuals detailing the uses and behavior of the symbology, and from SME interviews immediately preceding the flights. Nevertheless, the insights gained from a few hours use of the STRATA simulator clarified the symbol dynamics and interactions to a much greater extent. Furthermore, the ability to effectively discuss the symbology was vastly extended by the opportunity for both of the discussants to simultaneously observe and comment upon the symbology set in action.

Development of PRISMS I

As a result of the insights gained during the STRATA sessions, it became apparent that SME interviews would benefit greatly from the availability of a PNVS symbology simulator. In anticipation of a need for such a simulator, we had originally proposed a PRISMS simulator for the project in order to provide a series of useful, but static, graphics for presentation during the interviews. After the STRATA sessions, we performed a major upgrade of the PRISMS software to add a symbol animation capability and renamed it "PRISMS I," in expectation of additional versions. PRISMS I was first programmed in the VisualWorks Smalltalk language for the PC, and later in a Macintosh-compatible version. The animation features assisted enormously in clarifying the relationships among symbols and their movements.

Because a primary focus of Phase I had been the determination of appropriate rules to support a rule-based system for intelligent symbology management, we stressed the development of PRISMS I features for knowledge acquisition. Thus, PRISMS I was designed not only as an intelligent display-driving device, but also to include specific features for use in expert interviews. PRISMS I was configured with an easy-to-use dialogue for operation by Anacapa or Government personnel. The full set of PNVS symbols was provided in the HMD symbology window, and the Bob-up, Hover, Transition, and Cruise Modes could be selected by clicking a button in the HMD Control Window, as shown in Figure 2-3. The system could also be set to function in the "Intelligent Moding" role, responding to rules set in the PRISMS I Rule Editor.

In the lower-right window (Fort Rucker) of Figure 2-3 is a scrollable set of "Scenarios" that could easily be constructed, saved, and selected by the operator. The scenarios were used to input attributes (such as airspeed, altitude, bank angle) to set up the symbology window for simulating various activities, such as NOE flight or target acquisition. These same attributes could be used as "facts" by the Intelligent Moding system, in determining the appearance and decluttering of symbols.

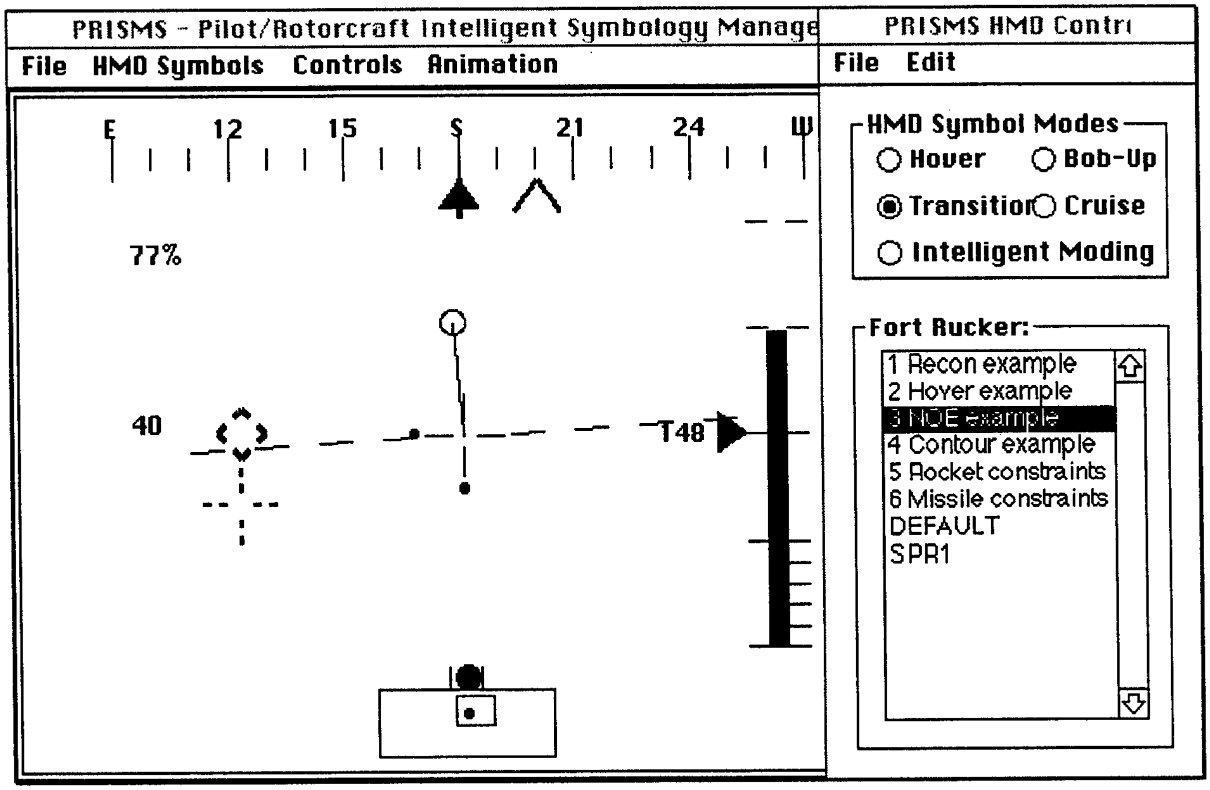


Figure 2-3. The PRISMS I Symbology and HMD Control Windows.

Selecting a scenario from the control window and pulling down the Edit Menu in the HMD Control window called up The Scenario Editor Window, which listed all of the attributes and current values of the attributes for the selected scenario, as shown in the left of Figure 2-4. Each attribute could be set in the Relation Editor Window, as shown at the right of Figure 2-4. For example, the "Wobble Range" and "Wobble Increment" entries permitted precise control over the range and speed of animation for each individual symbol.

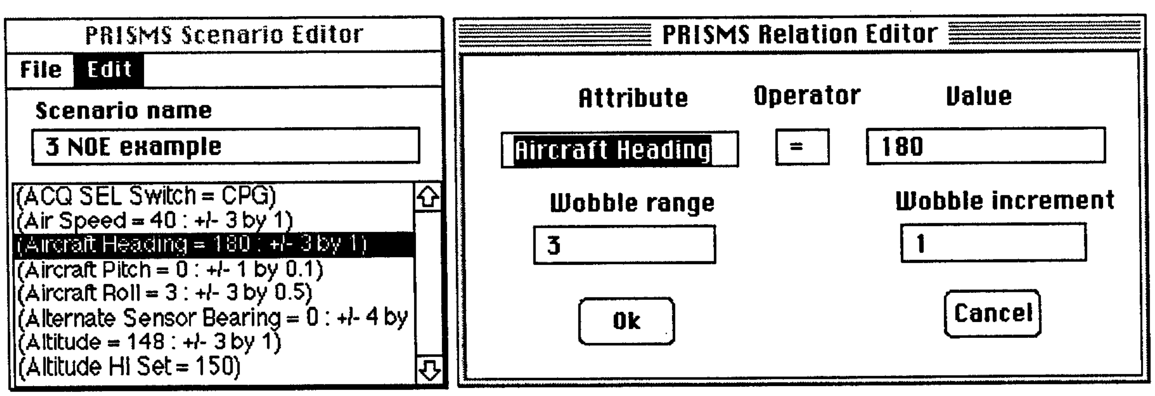


Figure 2-4. The PRISMS Scenario Editor and Relation Editor Windows.

The PRISMS Rule Editor permitted entry of sets of experimental rules for the conditional display of symbol elements. These rules were used to control the appearance and deletion of symbol elements in the Symbology Window when the Intelligent Moding option was selected. The simplicity of the user interface, shown in Figure 2-5, belied the power of the intelligent system software underlying the Intelligent Moding capability. For a simple example, Figure 2-5 shows the entry of a rule reading "IF the Aircraft Roll is greater than 5°, THEN the Horizon Line is ON." Any number or rules could be included in a set, and any number of sets could be stored. For purposes of exploratory development, these rules were instantiated by settings in the scenarios.

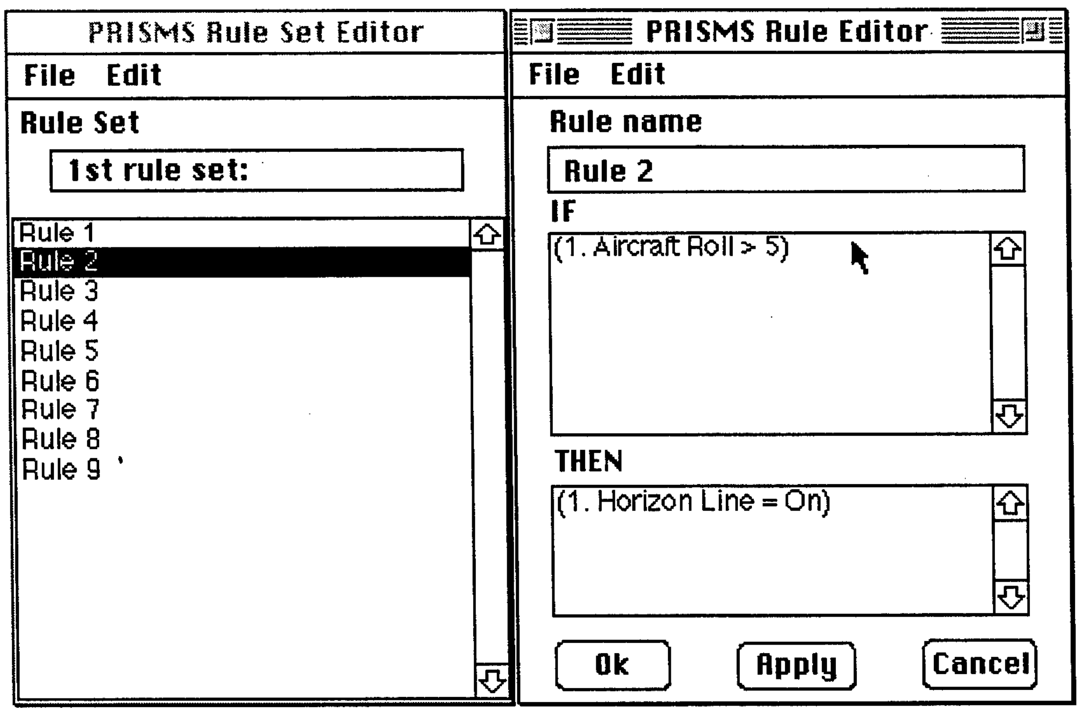


Figure 2-5. The PRISMS Rule Set Editor and Rule Editor.

AH-64 Instructor-Pilot Interviews

Interviews were arranged with 12 Instructor-Pilots (IPs) at Fort Rucker, Alabama, during February, 1996. The IPs were all from the 1/14 Aviation Regiment, and instructed the AH-64A Qualification Course. All of the IPs had extensive experience in operational units before their instructional assignment, averaging approximately 1900 rotary-wing flight hours and over 1100 hours in the AH-64. The IPs were interviewed individually, with sessions lasting 90 minutes to 2 hours.

Prior to the interviews, we had prepared comprehensive knowledge acquisition booklets with dozens of discussion topics based on our prior studies of mission requirements and near-term technology improvements. The booklets were prepared through extensive reviews of Anacapa's attack helicopter task analysis data, pertinent published literature, and our own in-house archives to identify

mission segments and tasks that might be better performed with the aid of new HMD symbology capabilities. We also reviewed our prior studies of new mission equipment packages (MEPs) that will permit (or require) new HMD symbology. Because of the breadth of the investigations, there was insufficient time for all of the IPs to discuss each of the topics. However, each topic was addressed by more than one IP, and some of the topics (such as current mode uses) were discussed by all of them.

The IP interviews were designed to be partly structured and partly free-wheeling, depending upon the topic areas and IP insights as we progressed. The interviews were divided into four parts. First, we briefly described the nature of the research project and its symbology improvement and intelligent moding objectives. Next, we discussed the current PNVS moding structure in detail, its advantages and disadvantages, typical usage patterns during a mission, and the potential applications of intelligent moding.

Subsequently, we began to explore the opportunities for advanced HMD symbology in support of both existing task requirements, and operational tasks as influenced by a broad range of new technologies expected to be on the next generation of attack helicopters. These discussions were subdivided into six categories: flight control and sensors, navigation and low-level flight, voice and digital communications, targeting and weapons management, aircraft survival equipment, and mission management.

For each of the operational tasks and new MEPs in a given category, we clarified our understanding of the requirements with the IPs and discussed the new types of symbols to potentially aid pilot performance. We presented a variety of situations, mission segments, tasks, and information elements, confirming our understanding of the requirements, and suggesting potential new types of symbols to aid pilot performance.

The discussions focused primarily upon HMD symbols that could be used to (a) identify tactical positions on the ground (conformally); (b) employ in communicating positions to the CPG, other aircraft, or the TOC; (c) permit computer systems, sensors, or other aviators to alert the pilot to a target, obstacle, or other position in the terrain; or (d) stay "head-up" in critical situations. For each potential symbol type, we attempted to determine the specific circumstances of its utility; its degree of improvement over current capabilities; and the most appropriate symbol forms, locations, and behaviors. For high-payoff symbols, we attempted to identify intelligent techniques for managing the symbol's appearance on (or removal from) the HMD.

In the fourth part of the interview, the IPs completed a brief survey of current IHADSS symbology. The survey asked the participant to rate the usefulness, frequency of use, and design quality of each IHADSS symbol.

Phase I Interview Results—PRISMS I Utility

PRISMS I was installed on a Macintosh 520c laptop computer for use as a knowledge acquisition device during interview sessions. The twelve IPs were immediately impressed with the fidelity of the PRISMS I symbology portrayal, especially with the symbol animation enabled, and several asked if it would be possible to obtain the software for use in their classroom instruction. They explained that no part-task simulator existed for AH-64 symbology, and they were forced to simply draw symbols on a chalkboard in the classroom.

The IPs told us that PRISMS I, with a set of appropriate scenarios, would be very valuable in teaching symbology interpretation for aircraft activities. In particular, they felt PRISMS I would aid in teaching symbology use during such flight activities as: hover, hovering turn, lateral hover, normal takeoff, rolling takeoff, NOE flight, slope operations, traffic pattern flight, normal approach, normal landing, and roll-on landing.

For the purposes of our interviews, PRISMS I served initially to introduce the Anacapa staff as cognizant of IHADSS symbology, and knowledgeable in attack helicopter operations, thus facilitating the discussions. During the course of the interviews, and as anticipated, PRISMS I provided the ability for the IPs and interviewers to point at or modify the behavior of the symbols on the screen, yielding much more effective knowledge acquisition than would be otherwise possible based on pilot recall and description of symbol behavior and pencil sketches.

Phase I Interview Results—Opportunities for Intelligent Symbology Management

As a result of the variety of methodologies employed in the Phase I effort, literally dozens of opportunities for HMD symbology enhancements and intelligent symbology management were identified. Below we describe just a few of these opportunities, using them as examples of the many types of valuable improvements that could be made.

Examples of Findings: Improvement of the Existing Mode Structure

We quickly learned that the Apache symbols are not necessarily used as described in the manuals and training materials. The usage patterns are often surprising, and helpful in interpreting specific information requirements and their correlates. For example, all of the SMEs indicated that the Cruise mode is rarely used by AH-64 pilots. Only "about one in twenty pilots use it at all," because information from the velocity vector (which disappears in the Cruise mode) is needed so frequently. In addition, the Bop-up mode is very rarely used, primarily because the current Doppler system is not sufficiently accurate in controlling the hover box. The hover box symbol is designed to mark the ground position under the aircraft at the initiation of a bob-up maneuver, so that remasking can be achieved over the same (obstacle-free) point. The navigation system inaccuracies, however, permit the box

to drift at a rate of up to 21 feet per minute, such that pilots cannot always trust it. As a result, the Transition and Hover modes are used most of the time.

One of the reasons the Transition mode is so frequently used is that the velocity vector can provide the necessary crab angle for straight-line flight in a cross-wind without any computations by the pilot. Although tracking the command heading symbol will lead to the next waypoint, following the command heading in a cross-wind will result in a curved flight path. To fly a straight path to the waypoint, it is only necessary to orient the aircraft so that the command heading symbol (Doppler caret) is positioned half way between the lubber line and the velocity vector, as shown in Figure 2-6. This capability is often useful in traffic patterns as well. In applications such as this, it does not matter that the Transition mode velocity vector is "saturated" (reaches the edge of the display area) at speeds above 60 knots.

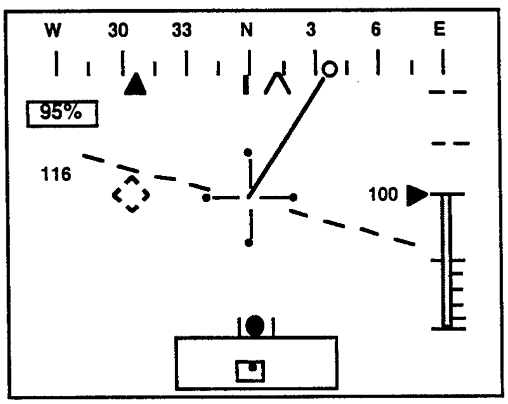


Figure 2-6. The Transition mode used to fly a straight path in a cross-wind.

In applications with slower speeds, such as during aircraft turns, the proportional length of the velocity vector in the Transition mode <u>can</u> be used as an immediate cue for adjusting speed: for example, two-thirds of the way to the edge of the screen is 40 knots, *groundspeed* (as opposed to the true airspeed digital readout). Yet another innovative use for the velocity vector is as an indicant of whether the aircraft is moving through terrain in NOE flight with a good nose-tail trim "so that you don't hit objects with the tail as you go by."

The Transition mode and Hover mode symbology differ in only two ways: the Transition mode adds a horizon line, and changes the velocity vector saturation point from 6 to 60 knots. The Hover mode's more sensitive velocity vector (and acceleration cue) are valuable for precise hovering both at airfields and in combat areas. Yet, the horizon line provides important information not only during contour and NOE flight, but for takeoff and landing at night. At takeoff, the pitch information from the horizon line is particularly valuable, and on landing, the "wings-level" information is necessary. On a normal landing, the Hover mode is used until the main gear touches the ground, when the pilot switches to the Transition mode to view the horizon line. This is of particular importance in a slope landing. The pilot is very busy at this point and fumbling for a manual mode switch is a burden.

Intelligent Symbology Management. Nearly all of the typical pilot's symbology changes are between the Hover and Transition modes. Many of the IPs indicated that intelligent symbology management could be applied to making this change, particularly since the change often occurs during periods of heaviest pilot workloads when thumb fumbling and switch direction confusions are the most prevalent and frustrating.

The IPs offered a variety of strategies for implementing this intelligent moding. Several indicated that it would be possible to simply change from the Hover to the Transition mode based on a groundspeed above 6 knots, when the Hover mode velocity vector saturates. On the other hand, as some IPs pointed out, the fact that the vector is saturated can itself be important information. Thus, others suggested making the change at 15, 20, 28, or even 32 knots. Additional study will be required to define an acceptable speed threshold.

Other IPs suggested more sophisticated approaches than using only ground-speed as the cue for the mode change. Such approaches included detecting a change in power setting to 10% above a baseline hover power (which changes from day to day), a change of 3° in downward pitch, or extreme pitch or bank changes to trigger the onset of the Transition mode. Several IPs noted that the "squat switch" in the landing gear might be used to initiate the mode change, if it is sensitive enough to detect touchdown (instead of full weight) on the gear; otherwise, another switch could be added to detect the initial contact of the landing gear.

Because only the horizon line and type of velocity vector change between the two modes, it is certainly reasonable to consider intelligent presentation of these individual symbols, dispensing with mode switching altogether. There are also some reasons for considering a manual (or voice) override capability as a pilot's option. For example, several IPs described the temporary selection of Transition mode during hover maneuvers to obtain a less-sensitive velocity vector for settling out aircraft attitude difficulties before returning to the Hover mode with its very sensitive velocity vector. On the other hand, rules could be developed employing attitude volatility to select the 6-knot or 60-knot velocity vector. As described below, though, such automation demands that effective cues be provided to prevent symbol confusions.

Examples of Findings: Avoiding Symbol Confusions

One of the recurring difficulties in designing an intelligent symbology management system is ensuring that its automated changes do not confuse the pilot. In general, symbol confusions among the current AH-64 symbol set are unusual. Although it is difficult for students to learn the use of the velocity vector and acceleration cue, the difficulty is based on the demanding nature of the task, not design problems with the symbols themselves.

The most critical confusions regarding symbol meanings in the AH-64 result from failure to recognize the current mode. The similarity of the four modes is shown in Figure 2-7. For example, the Hover and Transition modes are sometimes

confused (although the Transition mode includes the horizon line). Mistaking a 6-knot velocity vector for a 60-knot velocity vector (or vice versa) could well lead to inappropriate control inputs. One IP described a near-accident of this type using the current manual moding, where he mistook a 20-knot right-rear drift for a 2-knot movement. He strongly agreed with our suggestion that the two velocity vectors be shaped differently so that the 6-knot and 60-knot versions would be instantly discriminable. The two vectors could differ in thickness, continuity (solid versus dashed), or in the presence of a symbol at the end of the vector. This type of coding would provide especially important feedback in the case of intelligent symbology moding of the Hover and Transition modes, so that the pilot would be immediately aware that the mode shift had taken place.

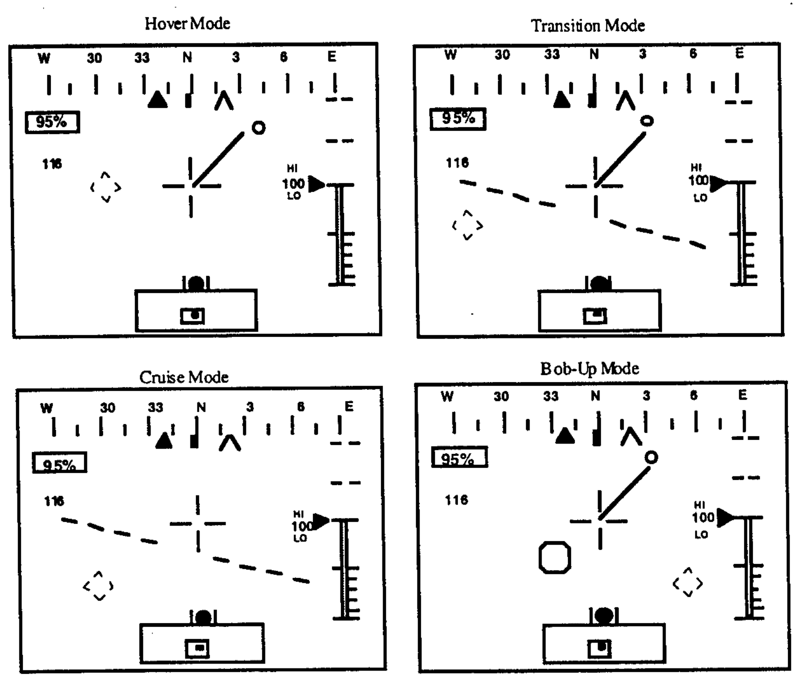


Figure 2-7. The four IHADSS mode screens: Hover mode, Transition mode, Cruise mode, and Bob-up mode.

Another potentially dangerous confusion among modes pertains to the Bob-up mode. When this mode is selected, the command heading symbol is locked to the aircraft heading, so that the pilot can remask the aircraft with the tail in the same direction as when the bob-up was begun. If the pilot forgets to deselect the Bob-up mode, and subsequently mistakes the command heading symbol for the next waypoint, "he could fly directly toward the enemy target he had been observing." These confusions could be avoided if the command heading caret was replaced by a different symbol (e.g., a dotted oval) in the Bob-up mode.

Yet another type of confusion, especially for students, stems from the off-axis viewing of the screen-fixed information. Symbology designed to be used along the aircraft axis may be spatially incompatible when the pilot turns his head to the left or right. For example, the velocity vector does not seem to move in the correct

direction when the pilot is looking off-axis. Nevertheless, the cure for these problems is not obvious. It could be "very disruptive and dangerous" if these symbols simply disappeared or changed radically when the pilot is looking off-axis. For example, "you need the velocity vector when you look to the side for lateral hover and for correcting fore and aft drift." These kinds of confusions, based on spatial incompatibilities of display and response pairs, are unlikely to be resolved or mitigated without insightful experimentation, such as that of Haworth & Seery (1992), and are at the core of any inventory of HMD research issues. Interview techniques alone cannot address these complex spatial issues.

Examples of Findings: Symbol Deletions and Additions

In order to best address the issue of decluttering the existing symbology presentation, the interviews were initially structured to identify the particular situational attributes that would lead to the *removal* of a symbol on the screen. In addition to a detailed discussion about the utility of every current symbol, 7-point rating scales were administered to the IPs to judge the usefulness, frequency of use, and design quality of every symbol.

In general, although the SMEs are very concerned about HMD clutter, almost none of the symbols were seen as "less than valuable." Only the radar altitude vertical tape and scale were clearly deemed potential candidates for removal. This was because they "take up so much screen space," the tape movements can be "a distraction," and because the radar altitude digital readout combined with the vertical speed scale are believed to provide more relevant information in a more directly useful form.

On reviewing the utility of each of the existing symbols in detail with each of the IPs, we found that removal of any of the existing flight symbology was unlikely to have a high payoff. Instead, we concluded that more could be learned by identifying the situations in which a *new* symbol might be temporarily helpful. Thus, the components of mission activities previously identified, including segments, functions, and tasks, and their required information elements, were used to explore symbol requirements in the interviews, in order to identify activities in which new symbols would clearly be useful or clearly not useful and to determine methods for intelligent symbology management. Suggested additional symbols generally fell into one of four categories: (a) information enhancement, (b) cautionary, (c) control setting, and (d) spatial/ geographic.

New Information Enhancement Symbols: Wind Data

In certain cases, information is readily available from the aircraft systems that would be useful to the pilot, but it is not presented because situational rules for its utility have not been defined. An excellent example is that of wind data. The Apache true airspeed (TAS) readout does not currently show the relative direction of the wind, although it does show a speed even if the helicopter is not moving. Wind direction data would be useful on the HMD, especially in the AH-64, because

"you can't really feel it [wind], even in a 30-knot cross wind because the Digital Automated Stabilization Equipment (DASE) is so effective." Knowledge of the wind direction and velocity might be moderately helpful in normal flight, although the Velocity Vector cues are usually sufficient.

In other situations, however, "wind can get you in trouble, such as in the cases of cranking or shutting down, takeoff with a tail wind, or descending into trees with a tail wind that might push you into trouble." Additional needs for wind data identified by the IPs included "rocket engagements," "hover taxi," "restricted area landings," "bob-ups," "landing at unfamiliar fields," and "hovering at night in the trees." Wind data are needed most of all to indicate head winds and tail winds, which are least detectable by the pilot (no aircraft attitude changes are available as a cue). Flying into the wind is also an important factor in aircraft recovery maneuvers, such as after loss of an engine.

The IPs suggested that a small symbol be placed near or below the airspeed symbol, as shown in Figure 2-8, to show the computed wind speed and its direction when in the Hover or Bob-up modes, when it is most important. Other pilots suggested that the indicator be placed in the lower-left corner of the screen. Several thought a numeric readout of wind velocity should also be included with the relative direction indicator. The pointer should "probably be damped" to prevent erratic behavior if winds are gusting.

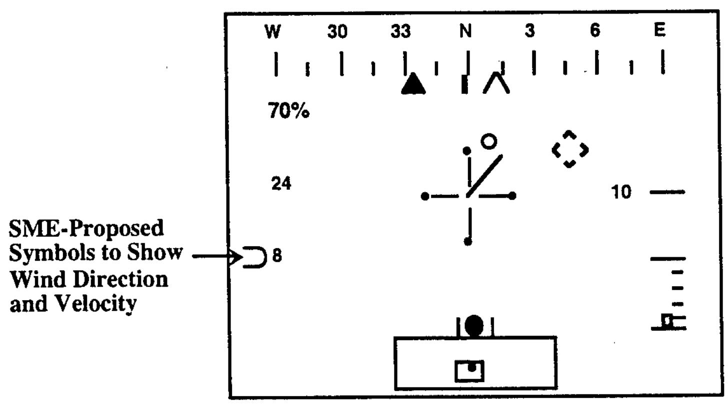


Figure 2-8. Candidate information enhancement symbol for wind direction (Hover mode).

Intelligent Symbology Management. There are several ways to use intelligent symbology management to cause a wind symbol to appear. For example, one IP suggested that it could be enabled "when you get to the point of change from positive to negative airflow, and aircraft speed is less than 40 knots." Other intelligent moding cues could be developed based on specific wind speeds, relative directions, and current aircraft altitudes and airspeeds. A verbal command to display this data for a few seconds would also be acceptable to most SMEs.

New Information Enhancement Symbols: Ground Speed Display

The IPs recommended that a ground speed display be provided to improve accuracy in determining expected time of arrival (ETA) at various waypoints. These times may be critical to mission success and aircraft survival. For example, inbound and outbound Passage Point arrival times must be very accurate (± 30 seconds accuracy is allowable) to avoid risking "friendly fire." The existing TAS display is, by definition, influenced by winds and does not provide ground speed unless the pilot "fails" the ADS. As an alternative, the CPG can be further burdened with a request to repeatedly calculate GS and tell the pilot to "speed up or slow down a little." Given the current speed, the Doppler system alone can be used to determine the ETA at a waypoint. However, the system does not "know" whether the aircraft is on time, or by how much it is ahead or behind schedule.

Some kind of a "speed bug" would be very helpful in these cases. It should also be possible to select a point other than the next waypoint for the calculation, such as a Passage Point several waypoints removed, and still calculate using the planned flight path (not a path directly to the Passage Point). A related aid would be a "time to leave" indicator to cue the pilot regarding when to depart holding areas, assembly areas, or other positions. Time should be shown in minutes and tenths of minutes.

Intelligent Symbology Management. The ground speed symbol could be moded to appear only when in flight between waypoints, rather than in hover or bob-up activities. Its appearance and behavior would be a joint function of the flight plan "currently" in effect, clock time, and ground speed. It could be used to present a "time remaining" display in minutes and tenths of minutes or, if straight-line flight is anticipated, the symbology could be presented as an airspeed requirement to compare to the TAS reading. The appearance and behavior of a "time to leave" indicator would also be a function of the flight plan currently in effect, clock time, and planned ground speed to subsequent positions.

New Information Enhancement Symbols: Planned Track Display

Although straight lines are drawn between the waypoints on the pilot's kneeboard map during route planning, it is seldom expected that the actual flight path will follow straight line, especially when terrain masking is desirable. Nevertheless, in order to deconflict the aircraft flight path with other friendly units and artillery fire zones, the S-3 may define a maximum distance from the straight line as a flight corridor of a given width.

The pilot often wants to know the distance of, and direction to, the straight line between two waypoints, so that he can quickly return to the planned leg and use the originally planned headings and speeds. If a digital map display were available, the solution would be obvious. But with the current map, such navigation issues are burdensome for both pilot and CPG. Currently, there are two ways to obtain this information: (a) the CPG must accurately identify the aircraft location and calculate the distance and direction for the pilot, or (b) the pilot must recall or otherwise retrieve the leg bearing and fly in the approximate direction of the line until the

Command Heading Caret lines up with that bearing on the Heading Scale. The SMEs were unable to offer a display format or location without more detailed consideration of all the implications.

Intelligent Symbology Management. Information is available from the navigation system to compute the relationship for the planned track, cross track angle, and the current aircraft position. This information could be moded to appear at a certain distance from the leg line, depending upon an acceptable flight corridor width, an ETA computation, or a verbal command from the pilot.

New Information Enhancement Symbols: Target Hand-Off Symbol

The IPs described three methods currently used to perform target hand-offs: voice with directions, voice with coordinates, and laser tracking. In the first method, the target range and bearing from one viewer is transmitted to the second aircraft and the range and bearing from the second aircraft is estimated based upon the relative position of the two friendly aircraft. In the second method, the CPG lases the target and the flight control computer (FCC) provides 8-digit grid coordinates which are transmitted by voice radio. The recipient of the coordinates enters them in the DEK and slaves the TADS to the coordinates. In the third and most accurate method, the CPG lases the target while the CPG in the second aircraft searches for, then tracks, the laser energy with the laser spot tracker. For each method, a price is paid in terms of performance time, potential detection by the enemy, or both.

Target hand-off could be improved with a "passive ranging" capability made possible through greatly improved head-tracker accuracy and the incorporation of digital terrain elevation data bases. The computation method is depicted in Figure 2-9, below. The computed coordinates could then be sent verbally, or by "data-burst" in which a conformal target marker is presented in the recipient's HMD symbology.

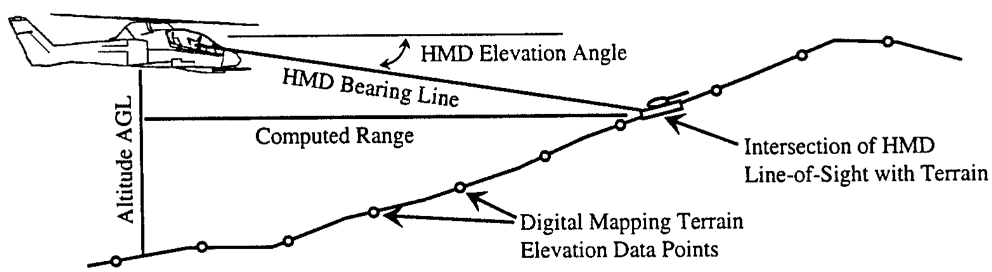


Figure 2-9. The geometry of passive ranging with the HMD.

A passive ranging capability with a cued LOS symbol would eliminate the possibility of detection of laser energy by the enemy, reduce the risk of detecting voice traffic, and speed the target hand-off process significantly. In addition, as the IPs pointed out, it would prevent the inadvertent lasing of friendly troops. As well, laser returns are often lost due to smoke and terrain obstruction. Although the pilot could send or receive targets in this manner, in most cases this is the domain of the

CPG because the magnified optics of the TADS permit more distant target identification and acquisition. However, the pilot may well use the gun for close-in targets, and passive ranging with the LOS reticle would immediately provide the range data necessary for the FCC to accurately compute the instantaneous impact point of the rounds. Currently he must either ask the CPG to lase the target for distance or "walk" the rounds onto the target to correct the error.

Intelligent Symbology Management. The target hand-off symbol could be set to appear automatically in the recipient's view, if data-burst to his aircraft. For the pilot's gun solutions, the passive range-finding and data entry in the FCC could be performed automatically when the pilot actions the gun and places the LOS reticle over the target. A visible change in the reticle could be used to indicate that the ranging solution had been achieved.

New Cautionary Symbols: Aircraft Control Settings

In general, panel-mounted advisories are acceptable to the pilots. However, in certain situations they may not be seen, and it may be more effective to present the caution message within the field of view (and perhaps add voice warnings). One such case is that of the parking brake setting. The physical position of the small parking brake handle (in front of and below the right knee) is the only cue to its status. The parking brake must be set to "on" for landings in unpaved terrain, but "it is easy to forget and leave it on when you get to a hard field." A roll-on landing onto a hard field will blow out one or both tires, possibly causing swerving and aircraft rollover.

The tail wheel lock setting is a similar case, although not as critical as the parking brake setting. The tail wheel can be locked to permit fore-aft wheel motion only. If the tail wheel is unlocked, it can cause fish-tailing during a roll-on landing. There is a warning light on the switch if it is unlocked, but it is hard to see under the glareshield at the left side of the instrument panel in the pilot's station.

Another useful advisory that could be added is a "DASE Off" message. The DASE facilitates control of pitch, roll, and yaw axes and should always be turned on before moving the aircraft. A caution light exists, but is usually too dim to be noticed in its current position. Although it is possible to fly the aircraft without the DASE, the aircraft is "very squirrelly" and could be dangerous, especially in formation.

Intelligent Symbology Management. An intelligent symbology management system would be extremely useful if it could detect situations in which such normal settings suddenly become dangerous, and display appropriate cautions to the pilot. Although the control settings could easily be sensed, the IPs were not certain how to best detect that a roll-on landing was in progress. It is probable that the message should appear at low altitudes (estimates ranged from 5 to 50 feet) and at ground speeds appropriate for a roll-on landing (about 30 knots), but additional cues should be identified. An intelligent moding of the DASE alert could be based on the "squat switch" which detects weight off the main landing gear.

New Cautionary Symbols: Obstacle Avoidance

Obstacles to flight should be a top priority for HMD display. The dangers of wire strikes and the difficulty in detecting wires at night are well known. Some areas of the world, such as Germany, are particularly dangerous due to the number of wires even at high altitudes. During planning, wires and other known obstacles are marked on maps for CPG reference. In the future, preplanned obstacles such as towers and wires will be stored with a variety of mission management data carried to the aircraft in digital form. New obstacle detection technologies are under development that can identify additional unmarked wires, poles, and towers in real time onboard the aircraft. To the extent possible, pilots want the symbology to "look like" the type of obstacle depicted, and appear in the field of view in the appropriate, real-world position so that the most appropriate actions can be taken.

Intelligent Symbology Management. Symbols to identify both stored and detected obstacles can be intelligently moded to appear to the pilot when the aircraft is at some given distance from the obstacle, and moving at a speed and in a heading likely to result in obstacle contact within brief periods of time unless evasive maneuvers are initiated.

New Control Setting Symbols: Radio Frequency Numerics

In many cases, temporary symbols or alphanumerics could be presented on the HMD to aid the pilot in control settings whose results are not otherwise obvious. Detection of the control actuation makes intelligent symbology management easy to achieve in this domain. Radio frequencies are one of the best examples of this category. In general, the pilot (rather than the CPG) is the one to make the radio calls. The pilot may need to change frequencies to contact a ground commander or another unit and, if the CPG is busy, the pilot must also do this himself. To change frequencies, the pilot must presently take his left hand off the collective to hold the cyclic, while twisting his body around to the right and using his right hand to turn the frequency selector knobs. The Army has not made any policy statements about this being an "acceptable" procedure.

In addition to this distracting contortion, it is difficult to read the frequency display, and may actually be impossible in mission-oriented protective posture (MOPP) gear. If the pilot could read the radio frequency on the HMD, he could at least keep his head up, even if the manual entry remained difficult. Changing transponder settings is similar to changing radio frequencies, except that the current displays are even more difficult to read. The use of a voice input procedure "would solve a lot of problems," but the pilot would still want to see the selected frequency for confirmation.

Intelligent Symbology Management. The activation of a radio frequency or transponder setting control could easily be used as the cue to present the appropriate frequency information in a head-up manner. The most likely area for display would be in the High-Action Display (HAD) at the bottom of the IHADSS field of view.

New Spatial/Geographic Symbols: Situation Awareness Cueing

Much of the information that an Apache pilot must process is related to friendly and enemy positions in space or on the ground. The current methods of correlating these positions with directions from the aircraft or specific sites on the earth are among the most difficult, error-prone, and time-consuming tasks the pilot must perform. Visual cueing to positions in the terrain is presently rather clumsy in the AH-64, even though much improved over the AH-1 Cobra aircraft. The procedure now used in the AH-64A to cue the pilot to a position in the terrain is as follows:

(1) If the positions are preplanned and entered in the FCC, the CPG will select them with the Data Entry Keyboard (DEK) and slave the TADS to them.

(2) To point out a position to the pilot that is not pre-entered in the FCC, the CPG must enter the 8-digit grid coordinates in the DEK or find the position by visual search and fire the laser to obtain coordinates. He then slaves the TADS to the position.

(3) The pilot can then set the ACQ SEL control to "CPG" so that the cued LOS reticle is the azimuth/elevation of the coordinate's location in the terrain, and use the cued LOS dots to acquire the cued LOS reticle. This cue, of course, is temporary, lasting only until the TADS LOS is redirected. It is at this point that the pilot is truly able to "look where the CPG is looking."

While this cueing procedure is effective, it demands that the CPG and his TADS be fully dedicated to support maintaining the pilot's situation awareness. In fact, the TADS is primarily in use for target acquisition and the CPG is heavily burdened with navigation, communication, and weapons handling tasks. There are many potential examples of spatial/geographic cueing to aid Apache helicopter pilots who "want to know where everybody is, friendly and enemy, and stay out of everyone's radar."

When a digital map becomes available in the cockpit, the pilot's designation of any map position could result in the appearance of a "pointer" symbol identifying that position in the real-world terrain. In a similar manner, the pilot's LOS could be used to identify a feature in the real world and enter a symbol on the digital map for immediate or later reference. Thus, the difficult problems of map-terrain correlation would be overcome. Even in the near term, without a digital map, it should be possible for the pilot to select any preplanned position for "virtual cueing," without involving the TADS or the CPG, as long as the head tracker and navigation system accuracy are improved. The next sections discuss some specific examples of situation awareness cueing—conformal waypoint markers, engagement area depiction, target position cues, mission management data, and aircraft survivability equipment (ASE) cues.

New Spatial/Geographic Symbols: Conformal Waypoint Indicators

The Apache pilot is almost entirely dependent on the CPG for navigation information except for the Command Heading Caret. As a result, the pilot's situation awareness is often less than optimal. Although he carries a simple strip map of the planned route on a knee board, he is usually unable to read it at night, and may try to memorize the flight legs (e.g., the heading to each new waypoint). The CPG must help the pilot by "talking him through" the waypoints. One of the highest payoffs for intelligent symbology management would be to use the HMD to automatically display conformal markers for real-world waypoints. This technological capability has already been demonstrated by the RAH-66 Comanche "lollipops" that unambiguously indicate the next two waypoints to the pilot, shown in Figure 2-10.

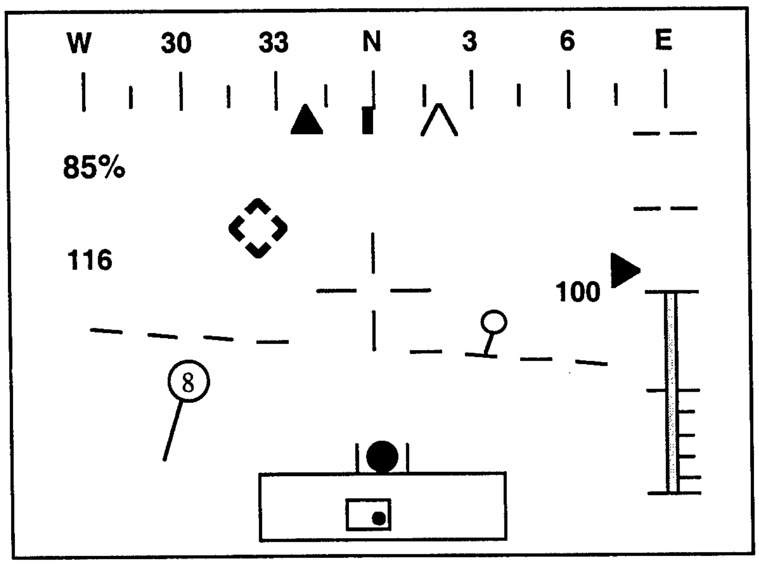


Figure 2-10. Conformal waypoint ("lollipop") symbols adapted from the RAH-66.

Conformal Waypoint Indicators were viewed by all the IPs in our survey as a valuable aid to visualization of the route in the real world terrain, reducing the requirements for guidance by the CPG, and reducing workload for both crewmembers. The pilots suggested that similar markers could be used for Assembly Areas, Holding Areas, FARP sites, and other friendly positions. A simple ball with the waypoint number and stem was judged to be an acceptable format. No specific shapes are required to encode other types of points because "everybody knows that number 10 is the holding area."

Intelligent Symbology Management. Intelligent moding of these markers could be controlled by current aircraft position with respect to planned waypoints. A voice command system should also be available to show the direction of any of the planned positions at any time.

New Spatial/Geographic Symbols: Engagement Area (EA) Depiction

An EA is planned in advance, but even if it does not change enroute, locating its position in the dark can be a problem. In addition, the lead aircraft in an attack mission designates firing sectors to prevent expending multiple weapons on a single target, and radios these sectors to the other aircraft. Sector boundaries are often hard to identify in the dark, especially without prominent landmarks to divide the EA. The problem is made even more difficult if the mission has been changed enroute, with new EA positions and boundaries assigned. Target engagement orders could be greatly simplified by a conformal depiction of the EA. This would help the pilot orient the aircraft appropriately, obtain masking, and prepare for engagement. The IPs state that both the pilot and the CPG should be able to see the conformal sector markers. Some pilots suggested that color coding be used to show specific firing sectors and no-fire zones.

Intelligent Symbology Management. Intelligent moding of the EA data presentation would occur with aircraft approach to the BP area. Sector data would be added upon transmission of a digital message from the lead aircraft.

New Spatial/Geographic Symbols: Target Position Cue

A target position indicator is sorely needed to supplement the PNVS symbol set. There is currently no way for the pilot to determine the location of targets without receiving directions from the CPG. The CPG can slave the TADS to an offset target and get continuous range and bearing data, but must continuously relay the data to the pilot by intercom, interrupting his target searching tasks. The pilot's Command Heading Caret is driven only by waypoints, not by targets. Waypoints are entered in the Doppler and targets are entered in the DEK. Unfortunately, the two systems do not share coordinate data. The pilot has cues neither for target direction nor target distance and he can become disoriented with respect to his relative orientation toward the target. As a result, he may mistakenly select routes or positions on the unmasked side of landforms. Target distances are important in selecting countermeasures and firing positions.

Conformal target position cues would greatly help in initial orientation of the aircraft, thus reducing TADS search times. Target cues could be provided to the pilot as small indicants in the Heading Scale when at long distances, and as conformal cues to a specific location in the terrain when approaching more closely. The IPs suggested that symbols should be kept simple, such as an "X" rather than pictorial icons showing target type. Special symbols could be used to represent ADA threats, and for JAAT operations, to show the fixed-wing aircraft the target.

In addition, a digital terrain elevation data base, if available, could be used to continuously compute intervisibility from known target positions in the terrain. This approach would be more effective than waiting for the APR-39 to indicate that masking has not been maintained. One simple method of portraying masking is to depict the target symbols in dashed lines if the aircraft does not have intervisibility and solid lines if intervisibility exists. Such an approach also serves to cue the pilot

that the target indicated by a conformal symbol does or does not reside on the nearest landform in the direction of the target.

Intelligent Symbology Management. The appearance of target symbols of both types could be intelligently moded, appearing either at a given target distance, or on arrival at positions in the planned route of flight. If there are many targets, a declutter capability may be necessary, perhaps through a voice command such as "Threats off." The intelligent masking symbol management would be based on continuous intervisibility computations.

New Spatial/Geographic Symbols: Mission Management Data

As noted above, the pilot carries only a very simple strip map of the flight route, and is dependent upon the CPG for most navigation functions. As a result, it is difficult for the pilot to maintain tactical situation awareness in the battle area. This problem becomes much more critical when unplanned maneuvers and route changes are required, as a result of enemy activity blocking a planned path into or out of the BP. It is important not to stray across international boundaries, division or brigade boundaries, phase lines, near enemy (or friendly) ADA units, or into planned artillery firing zones. Most pilots agreed that it would be extremely valuable to have warnings of such dangers presented by conformal HMD symbology. The symbols should be sufficiently attention-getting to be easily noticed, but block as little of the field of view as possible.

Intelligent Symbology Management. The mission management symbols could be intelligently moded to appear only when the aircraft is at a select distance from the danger, (e.g., "1 to 3 kilometers") and flying at a speed likely to result in crossing boundaries within certain periods of time (to be determined).

New Spatial/Geographic Symbols: Aircraft Survival Equipment Display

The APR-39 radar warning device in the AH-64A provides voice warnings of threat activity and their relative direction, such as "Searching - 2 o'clock." In order to permit rapid masking of the aircraft, instead of receiving just a numerical bearing to the threat, it "would be a great idea" to use the HMD to paint a symbol in the field of regard, perhaps supplemented with a 3-D audio cue, to more naturalistically represent the weapon's position in space. Since the APR-39 does not provide distance-to-weapon information, the symbol would have to be a vertical line rather than a discrete point on the terrain. Most of those interviewed indicated that the HMD symbology could give a spatially superior indicant of direction with a line or some other marker so that the pilot can either orient the aircraft appropriately for use of the gun, jammer, chaff, or flares, or prepare to deploy to cover. Unlike a spoken warning, a visible line provides a continuous indicant of the direction of the threat, even as the pilot changes his heading to respond to the threat.

Intelligent Symbology Management. The symbol should appear automatically with the APR-39 warning, and remain on "only for a few seconds" while the pilot weighs his alternatives and chooses a course of action. If the threat is a preplanned

target, however, distance information will be available to position a conformal target indicator symbol.

Phase I PNVS Symbology Survey

The PNVS symbology set used with the IHADSS has, for the most part, been very well designed according the SMEs interviewed at Fort Rucker. That is not to say that it is necessarily easy to learn and use. To find out more about the SME's impressions of specific symbols, we asked them to rate each symbol on three seven-point scales. The SMEs were requested to check a box scoring the utility, frequency, and design quality of each of the symbols in comparison with the entire symbol set, as shown below:

Of all of the information presented on the IHADSS, this is one of the

Least useful	1	2	3	4	5	6	7	Most useful
Infrequently used	1	2	3	4	5	6	7	Frequently used
Worst-designed symbols	1	2	3	4	5	6	7	Best-designed symbols

The overall results of this survey are summarized in Table 2.2 on the following page.

These ratings served to confirm the interview findings, demonstrate the consistency of IP impressions, and provide an objective basis for comparison of the relative merits of the various symbols. The utility and frequency ratings are expected to be valuable in aiding decisions regarding intelligent symbology management techniques for these symbols.

At the conclusion of the Phase I period of performance, we had met and, in many respects, exceeded our original project objectives. We had (a) determined the clear utility and feasibility of an innovative, intelligent symbology management system, (b) developed a unique portable HMD symbology simulator with intelligent symbology management capabilities, and (c) expanded and verified our findings with intensive interviews with thirteen expert AH-64 Apache pilots. The combined results of our several coordinated research methodologies had led directly to the conclusion that such a system could and should be developed, and that it should be broadly applicable to current and future aircraft.

In many ways, Phase II activities were a direct outgrowth of the successful methods employed during Phase I. The objectives and analyses were expanded to address many more pilot functions and tasks, the lap-top simulator was replaced by a sophisticated flight simulator with aircraft controls and an immersive HMD display, and the successful interviews with SME's were expanded to include a range of experiments and demonstrations to determine the utility of new symbology and the appropriate cues for intelligently moding these symbols.

Table 2.2
PNVS Symbols Ranked by Utility, Frequency of Use, and Design Quality

Rank	Symbol	Utility	Symbol	Frequency	Symbol	Design
1	Missile Const Box	6.67	Velocity Vector	6.58	Rate of Climb Ind	6.33
2	Velocity Vector	6.67	LOS Reticle	6.50	LOS Reticle	6.25
3	Rocket Strg Cursor	6.58	Acceleration Cue	6.50	Airspeed (Digital)	6.25
4	LOS Reticle	6.58	Rate of Climb Ind	6.50	Skid/Slip Ball	6.25
5	Rate of Climb Ind	6.50	Missile Const Box	6.42	Missile Const Box	6.17
6	Horizon Line	6.50	Heading Scale	6.42	Heading Scale	6.17
7	Heading Scale	6.50	Fixed Lubber Line	6.42	Fixed Lubber Line	6.17
8	Fixed Lubber Line	6.50	Vertical Speed Scale	6.42	Radar Alt (Digital)	6.17
9	Radar Alt (Digital)	6.42	Airspeed (Digital)	6.33	Velocity Vector	6.08
10	Weapon Control	6.42	Skid/Slip Ball	6.33	Acceleration Cue	5.92
11	Skid/Slip Ball	6.25	Horizon Line	6.25	Rocket Strg Cursor	5.83
12	Range/Rng Source	6.25	Radar Alt (Digital)	6.25	Vertical Speed Scale	5.83
13	Airspeed (Digital)	6.17	Rocket Strg Cursor	6.17	Range/Rng Source	5.75
14	Acceleration Cue	6.17	Command Heading	6.08	Weapon Control	5.67
15	Vertical Speed Scale	6.17	Weapon Control	6.08	Command Heading	5.50
16	Engine Torque	6.00	Weapon Status	6.00	Horizon Line	5.50
17	Weapon Status	6.00	Range/Rng Source	5.92	Weapon Status	5.08
18	Command Heading	5.92	Engine Torque	5.50	Field of Regard Box	5.00
19	Sight Status	5.42	Sight Status	5.33	Field of View Box	4.92
20	Alternate Sensor Brg	4.92	Field of View Box	4.42	Cued LOS Dot	4.75
21	Field of View Box	4.33	Alternate Sensor Brg	4.25	Sight Status	4.75
22	Field of Regard Box	4.17	Field of Regard Box	4.00	Cueing Dots	4.42
23	Cued LOS Dot	4.08	Cued LOS Dot	4.00	Alternate Sensor Brg	4.33
24	Radar Alt Bugs	3.92	Radar Alt Bugs	3.58	Engine Torque	4.25
25	Cued LOS Reticle	3.75	Head Tracker	3.17	Head Tracker	4.17
26	Head Tracker	3.33	Cued LOS Reticle	3.17	Cued LOS Reticle	4.08
27	Cueing Dots	3.33	Radar Alt V. Scale	3.08	Hover Position Box	4.08
28	Radar Alt V. Scale	3.25	Cueing Dots	2.42	Radar Alt Bugs	4.00
29	Hover Position Box	2.83	Hover Position Box	2.00	Radar Alt V. Scale	3.92
30	Radar Alt V. Tape	2.33	Radar Alt V. Tape	2.00	Radar Alt V. Tape	3.08
	Mean Rating	5.33		5.14		5.22

Section 3: Symbology Management Issues

There are two major dimensions of symbology management: the method of mode switching and the method of information organization. The method of mode switching is that cue, somehow initiated by the pilot or some non-human portion of the system that causes symbology to change in content or behavior. The method of information organization describes the manner in which symbology sets are subdivided into groups, differentially retrievable by the mode switching cue. These two topics will be described in more detail in the following pages.

Comparisons of Potential Pilot-Operated Mode Switching Methods

Manual Mode Controls

The number of potential manual mode-change input devices and methods are legion. Nearly any type of control could be pressed into service for these selections, including controls that have existed for decades including push-buttons, toggle switches, rotary selector switches, and thumbwheels. Because symbology mode changes may be most needed when manual workload is greatest, however, it is reasonable to limit consideration of these methods to those that can be employed while both hands are engaged with the collective and cyclic controls. otherwise known as "HOTAS," for "hands on throttle and stick." or, for rotorcraft, "HOCAC" for "hands on cyclic and collective."

The placement of controls on the cyclic and collective, however, does not necessarily ease the degree of manual workload associated with their use. In both fixed wing and rotary wing military aircraft, the two grip control surfaces are crowded with diverse input devices. Psychomotor demands are a serious human factors problem in high-performance aircraft. The demands are so great that HOTAS procedures in general have been likened by pilots to "playing the piccolo" in reference to the rapid and complex finger movements that are required in the F-16C and F-15E (Campbell and Rogers, 1993).

In the Apache helicopter, manual switching might seem simple because there are only four modes and nearly all of the pilot's typical symbology changes are between two modes: Hover and Transition. Nevertheless, this change often occurs during the periods of heaviest pilot workloads when thumb "fumbling" and switch direction confusions are the most prevalent and frustrating (Rogers, Spiker, & Asbury, 1996). For example, on landing, the Hover mode is used until the main gear touches the ground, when the pilot switches to Transition mode to view the horizon line. This is of paramount importance in the slope landing during which the pilot is very busy controlling the roll rate and groping for the manual mode switch is an undesirable burden. Furthermore, if a variety of new HMD symbols are to be considered for use in advanced rotorcraft, the single thumb control would not provide enough control options, and it is doubtful that a sufficient number of

additional controls could be added to the cyclic or collective and still be located within convenient finger and thumb reach.

Alternate Psychomotor Controls

In a visionary paper presented to the Human Factors Society over a decade ago, Furness (1986) described a revolutionary virtual crew station entitled the "Super Cockpit." At the time, Furness noted that although some design criteria might be derived or extrapolated from existing research findings, "most will require a new generation of human factors research to acquire the empirical data" necessary for their development. With reference to control inputs, the paper itemized five possibilities to be used in combination within a virtual cockpit. These five are still the primary contenders for alternate psychomotor controls, and are briefly described below.

(1) Head-aimed control. In this technique, the pilot can use the HMD to position a screen-stabilized reticle over a virtual (cockpit referenced) switch box and press an enabling switch to select the function. We have worked (on another project) for several years on this concept and find it surprisingly effective (Rogers, Spiker, & Fischer; 1996). Typical acquisition times, depending upon the size of the target and angular distance of the head movement were approximately 1 second, as shown in Figure 3-1. This movement was a full-screen head movement of 10° angular rotation. Times are about 20% longer for such movements than for 5° movements, even though more rapid head velocities are reached in the longer movements. Target acquisition times for horizontal and vertical movements are approximately the same, although diagonal movements increase acquisition time by about 18%.

As might be supposed, target acquisition times are strongly dependent upon accuracy requirements. Had our cursor been only slightly larger (about 0.34 inches instead of 0.29 inches in diameter, typical target acquisition times would have been reduced by about 150 msec. Any amount of system lag between head movement and cursor movement is destructive to performance, even though the user may be unaware of the lag. We found there to be a linear relationship between lag and target acquisition time such that each millisecond increment in lag between head movement and cursor response increased acquisition time by about 7 milliseconds

Once the cursor has reached the target, the stability of the head-controlled cursor has been shown to be reasonably good. For example, Figure 3-2 shows a ten-second time history of the cursor stability without external perturbations such as vehicle movement or vibration. Such findings suggest that using head dwell time to actuate a control (as opposed to an additional manual switch) might prove feasible.

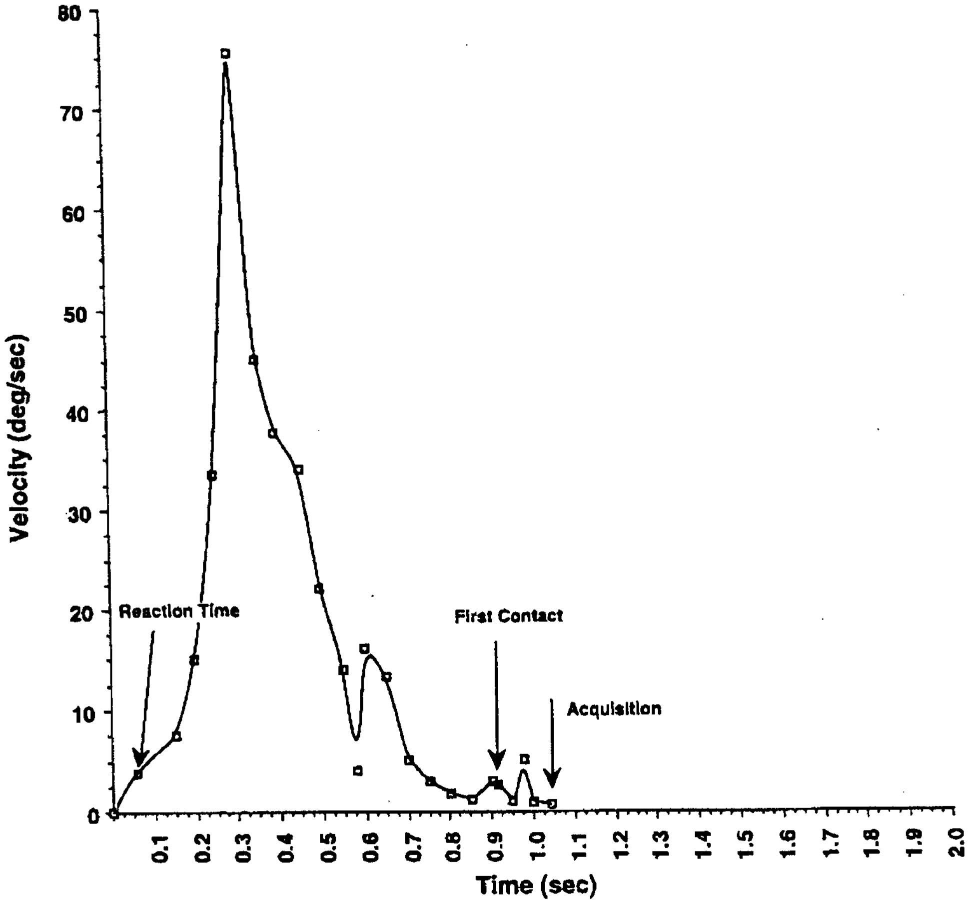


Figure 3-1. Head movement velocity profile for a 10-degree head movement to place a cursor on a small target (Rogers, Spiker, & Fischer; 1996).

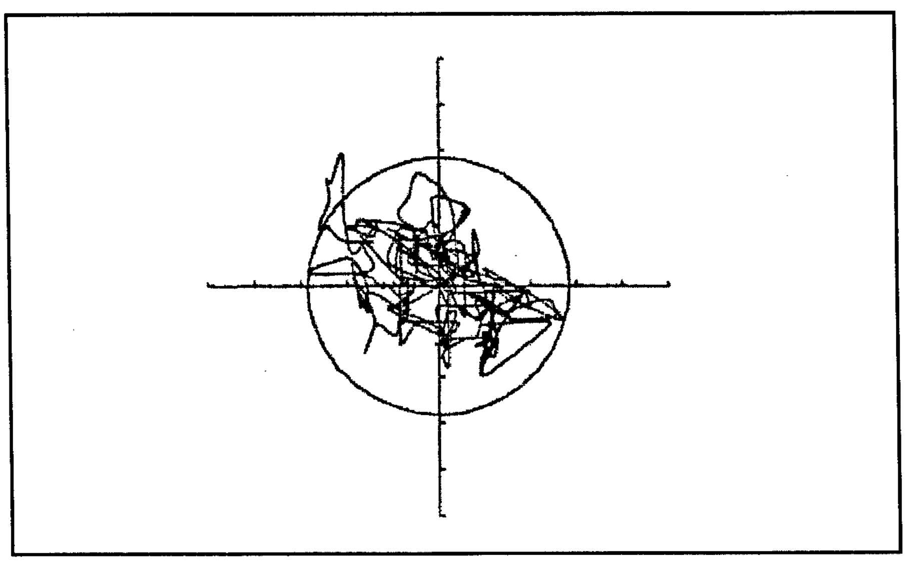


Figure 3-2. A 10-second time history for one subject aiming at a stationary target with a head-mounted sight. The circle represents 0.57° or 34 arc-minutes (Wells & Griffin, 1987).

In our studies, the head-tracked cursor technique was shown to be considerably faster than the thumb-operated cursor control currently in use in the F-16C and F-15E. However, the extent to which buffeting and high-g maneuvering (in the fighter aircraft) or vibration (in the helicopter) would effect accuracy or even usability of this approach has not been fully evaluated. Another potential disadvantage is the clutter introduced by an array of virtual icons used for selection of symbol display options. Such an array could be positioned in a head-down position within the cockpit to reduce clutter of the outside terrain, but would then lose the primary virtue of the HMD: head up and out of the cockpit.

(2) Eye control system. Using a sensor to determine the instantaneous position of the pilot's eyes combined with head position data would identify eye fixation angles within the cockpit so that the pilot could look at either virtual or real switches and manipulate them. With this approach, an icon would appear in a known position on the HMD field of view. Using the independent eye tracker, the pilot can actuate this "switch" to change symbology modes by maintaining his gaze on the icon for a set period of time. Variables to be considered with this option include the screen location of the switches, their size and shape, as well as the gaze time required for actuation. Alternatively, the pilot could actuate them with a verbal command such as "on," "off," or "select," or use a dedicated manual switch to activate or deactivate the switch currently being viewed.

Calhoun & Janson (1986), for example, performed an experiment in which six subjects selected various discrete switches on the front panel of a cockpit simulator during a manual target tracking task. Their subjects were instructed to direct their gaze at the switch designated by an auditory cue and then to make a "consent input" (in the form of either a manual response or a verbal utterance). In the control condition, simulating a standard manual control, subjects simply actuated the switches with their left hand. The authors' analysis of mean switching time showed no significant differences among the three switching methods. Since the eye control method was not slower than the manual method, the authors concluded that an eye-tracked control system would be a feasible option when hands-off control is needed. The authors suggested further study of the advisability of having multiple control mechanisms available, so that the pilot could choose which method to employ.

The eye control system is similar in concept to the head-aimed control, but uses existing and very well-trained skills whereas head tracking is somewhat less natural and some practice is required to master the skills. Furthermore, eye movements are considerably faster than head movements, so the selection of the functions should theoretically proceed more rapidly, although this was not the case in the Calhoun et al. study. It is important to remember, however, that the technologies used for head tracking have proved over the years to be robust and survivable in the cockpit environment, while the same claim can not yet be made for the eye-tracking technologies.

(3) Voice-actuated control. The pilot can utter specific control commands to a system monitoring his speech when a separate switch, virtual or physical, is

enabled. Although a great deal has been written about voice technology in recent years, the classic analysis of the utility of voice technology in Army helicopters remains that of Dr. Alan Spiker (1986) of Anacapa Sciences. His report describes the results of a series of human factors analyses designed to evaluate the feasibility of applying voice technology to Army helicopter cockpits. The primary purpose of this work was to specify the functional requirements to be satisfied by such applications, and to identify those tasks for which aviator workload would, and would not be, reduced by this technology. The end result of this eight-month effort was a set of recommendations and guidelines that delineated the Army aviation task areas in which application of speech recognition and speech synthesis technology is likely to have either high payoff, low payoff, or no payoff.

It is important to note that in conducting this study it was assumed that the technology itself was mature and functioned rapidly and without error. Thus the results are not limited to the technology of the 1980s, but are still quite valid. In short, it was found that the major obstacles to the application of voice systems are task- and user-based rather than technological. The primary factors ultimately limiting voice system applications are human factors rather than technological ones.

First, voice technology is most applicable to tasks that impose high sensory/motor workload and least applicable to tasks requiring high cognitive workload. Voice systems can only provide input to a control device or report the output from an external sensor; hence, they require an existing level of automation to be applicable. Since these systems do not automate decision-making for the aviator, their use will necessarily be restricted to tasks in which the primary workload is sensory or motor rather than cognitive.

Second, due to recent avionics enhancements, much of the aviator's workload is now cognitive rather than sensory or psychomotor. As avionics enhancements have addressed many of the sensory and psychomotor difficulties found in previous cockpits, the cognitive demands imposed by the more sophisticated equipment are now the primary bottleneck to improving the workload situation in the cockpit. Some of the most demanding cognitive tasks include target tracking, monitoring approach areas, confirming navigation data, aligning sensor sight, selecting sensor search area, verifying launch constraints, and monitoring laser designation codes. Unfortunately, these tasks are also the most resistant to automation through voice since data integration rather than I/O reduction is needed most.

The project methodology included analysis of the overload frequency and duration data from the 60 high-workload tasks in the LHX data base to quantify the extent to which voice automation would reduce aviator overload. The amenability of each task to workload reduction via voice automation was determined by jointly considering (1) application-relevant findings from research literature, (2) first-hand discussions with aviators, and (3) human factors application principles. Regarding the latter, voice technology was considered applicable to a particular task when:

- the combined visual/motor workload is high
- the psychomotor movement is awkward

- visual scanning is difficult
- the task involves extended psychomotor activity
- a complex auditory discrimination is required
- a complex visual discrimination is required.

On the other hand, negative decisions concerning the application of voice technology were based in part on the following criteria:

- unaided visual scanning is required
- the task is primarily cognitive, decision-oriented
- periods of sustained voice communication are required
- rapid fine motor movements are needed
- psychomotor adjustments of nonautomated systems are required
- the task involves recall of information from memory.

Despite the overall poor prognosis for cockpit applications of voice systems, four task areas were identified for which voice technology should prove quite useful: display of threat identification and location information; display of aircraft heading, altitude, and fuel under mission-specific conditions; automatic recording of all radio voice messages; and spoken input as an alternative to keyboard entry of digital target handoff messages.

Human factors analyses revealed that a wide array of task areas would benefit little from voice applications, including: selection and control of weapons and radio; operation of sensors; speech display of checklist information; entry of target and navigation data; display of warnings, cautions, and advisories; and selection of alternative message formats. In addition, five task areas would be poorly served by voice automation: target tracking, weapon release, monitoring of terrain and non-automated cockpit equipment, flight control, and display of status information.

The utility of application of voice-actuated control for the selection of symbols or symbology modes is not clear-cut. HMD symbology may be called for to support a range of different tasks, some of which meet the criteria for voice technology application, and some that do not. The pilot's manual output burden is certainly reduced, but his cognitive activity may be interrupted. Since such a system does not automate decision-making for the aviator, its use provides the most benefit for tasks in which the primary workload is sensory or motor rather than cognitive.

Since sensory and motor tasks in the cockpit are becoming overshadowed by cognitive tasks, at least in terms of pilot workload, the ideal option would seem to be an automatic, intelligent system to automate decision-making and present and remove symbology in the most effective manner. Nevertheless, most of the pilots we have interviewed over the course of this project would demand either a manual or a voice control mechanism to override an automated symbology presentation system when necessary. Given the shortage of space for supplementary manual controls, the voice command option remains a viable one.

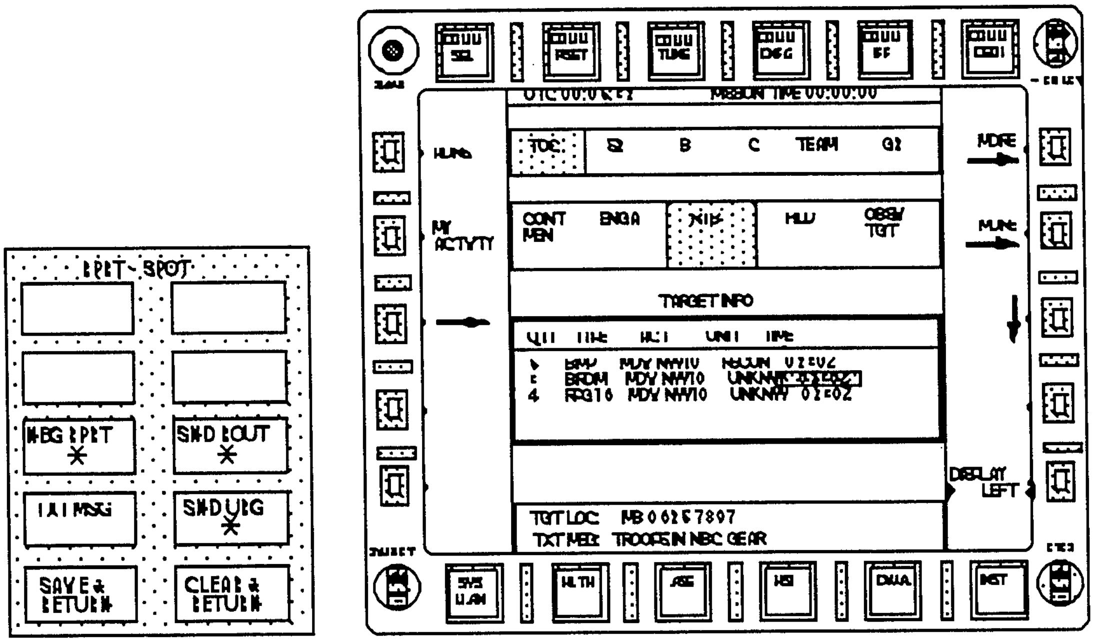
(4) Touch-sensitive panel. Furness (1986) suggested the use of a touch-sensitive panel such that the pilot places a finger on a physical surface area "with superimposed cockpit-stabilized visual information" from the HMD and uses these "virtual buttons" to call up information or other cockpit switching functions. In accordance with the pilot's finger pressure on various alternatives, "touch panel regions are redefined for different additional panels which may be called up and windowed within the display." In effect, a multi-function display can be created with virtual labels instead of self-illuminated CRT or flat panel displays with adjacent buttons of pressure-sensitive overlays. Although the authors have not found any experimental comparisons of virtual labels on touch panels with other control systems, self-illuminated touch screens have been developed and studied.

Liggett, Kustra, Reising, & Hartsock (1997) compared the use of a thumb-controlled cursor, a head-tracked cursor, and a touch-sensitive screen for the designation of targets on a 10 inch by 10 inch CRT screen and found that the designation via the touch screen was significantly faster than either of the other two devices. The nature of the task, however, was not ideal for evaluating rapid response times of skilled motor outputs, since the complexity of the task typically required over 15 seconds to perform in full and had a number of cognitive elements. Furthermore, because the one-size helmet fit some subjects poorly, a fair evaluation for the head-tracker mechanism was not permitted. Nevertheless, it is evident that a touch-sensitive screen can be an effective input device if HOTAS or HOCAC is not required.

The touch-sensitive menu concept has been used to good advantage in the RAH-66 Comanche design (Friedman, Hamilton, Rice, and Stockdale, 1992). Although the control labels are self-illuminated rather than virtual, the ten software controlled switches known as the Touchscreen Menu Items (TMI) are located for easy access in the lower portion of the leftmost multi-purpose display.

Each switch can provide a variety of types of functions and is graphically coded to show whether it is an "action," "toggle," "menu prompt," "state select," or "keyboard prompt" switch. The codes, labels, and functions change to reflect the available options for the operations underway, thus providing an endless number of possible inputs within a very small panel space. For example, Figure 3-3 shows the TMI configured for use with the "PIREP" window of the multi-purpose display. The asterisks on the TMI indicate "action" keys that command the system to perform a one-time task such as "send-urgent."

The TMI, while too complex to be described here in detail, is a good example of striving to meet the challenge of maintaining pilot awareness of the automatically changing system status. This is especially vital given the wide range of control and display interface possibilities and the limited amount of cockpit space. While the TMI does not employ virtual labels, the content and format of the control labeling, the compatibility of its structure with the task at hand, and its effective use of human-computer dialog principles could be expected to be much more important than the source of the illumination itself.



TMI SMD

Figure 3-3. The Comanche TMI adjacent to the multi-purpose display.

(5) Virtual hand controller. Using a special glove and a magnetic tracker, hand position and orientation can be sensed in six degrees of freedom. Furness (1986) suggested that "When the hand is put into a predetermined volume or region within the cockpit, a three-dimensional virtual control panel is windowed into the visual display. The pilot then activates functions or makes verinier adjustments by moving his hand or placing a finger over the virtual switch." Wearing such a device, the pilot could activate or adjust virtual switches with auditory, visual, or even tactile feedback of his actuations.

Most applications would first require measurement of the position and orientation of the forearm in space. To meet this requirement, some type of optical, magnetic, or ultrasonic tracking sensors are positioned on the glove wristband or back. In one study, (Liggett, Reising, Beam, & Hartsock, 1993) compared an ultrasonic hand tracker with a joystick and found that the hand tracker provided the best performance with respect to total target designation time, (although the mean time difference between the two devices was small). The nature of the task, identifying a target in a three-dimensional space was more compatible with a hand movement in space than the required inputs to a 3-axis joystick device.

The technology continues to improve and in addition to simple location of the hand, flexible sensors are used to accurately and repeatably measure the position and movement of the fingers and wrist. The sensors are extremely thin and flexible and produce almost undetectable resistance to bending. The more advanced models feature bend sensors on each finger, abduction sensors, sensors measuring thumb crossover, palm arch, wrist flexion, wrist abduction, and the flexion of the distal joints on the four fingers. An example of one such device is shown in Figure 3-4.

The authors were unable to obtain any experimental studies employing such a device in a cockpit setting.

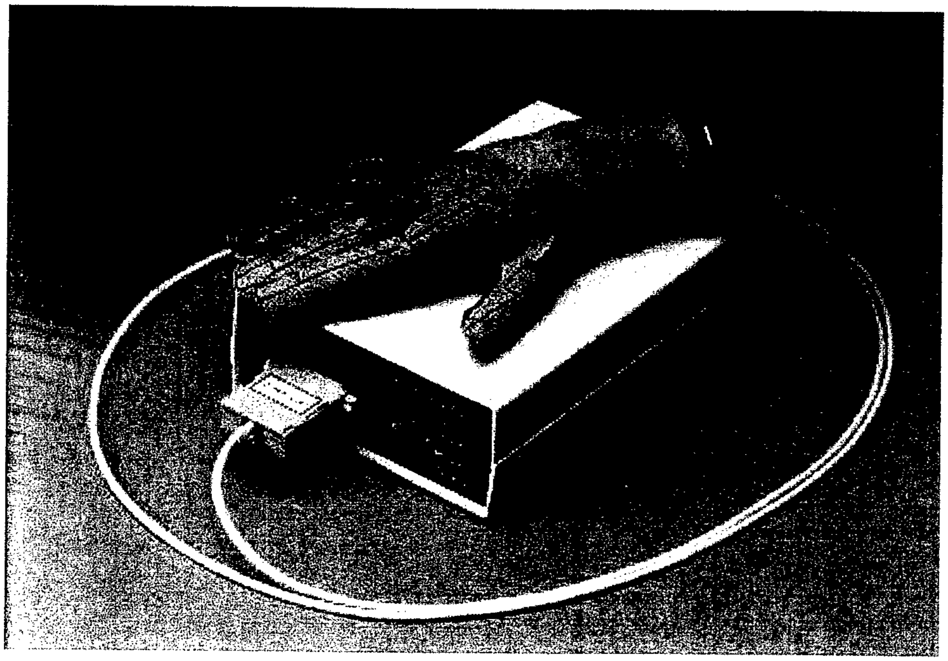


Figure 3-4. The "CyberGlove" (Virtual Technologies).

Like the touch-sensitive screen, it is evident that a virtual hand controller can be an effective input device if HOTAS or HOCAC is not required.

Summary. The existing control approach, and five new control options described above have been considered. A brief summary of their advantages, disadvantages, and associated workloads are presented in Table 3.1. From this summary, it can be seen that none of these control technologies is ideal, and each has its limitations. Use of the touch panel and virtual hand controller require that one hand be moved from the flight controls. Head-tracked and eye-tracked control may suffer from aircraft vibration. Voice recognition control requires that the pilot memorize the set of available commands, and may interfere with voice communications. There is very limited space for additional manual (HOCAC) controls, and manual workload is already very high.

The key issue at hand is how well these control technologies might perform when employed for the selection of symbols or symbology sets immediately needed by the pilot. In one regard, the requirement is simple: the symbols typically need only to be turned on or off, and such discrete inputs are more easily dealt with than complex motor tasks such as target tracking. When only four symbol modes are available, as in the IHADSS symbology, a manual control is adequate, although not ideal given the current manual workload requirements.

However, if consideration is given to controlling symbols individually, there is a large number of symbols potentially in need of such control, and the manual control method (whether real or virtual) is unlikely to be feasible. In this case, either

the options must be visually presented to the pilot for his selection, or he must recall the necessary command from memory. Presentation of a symbol list (whether by text or icon) leads to visual clutter of the HMD field of view if the list is presented head-up, and a loss of view of the outside world if presented head-down. The head-tracked, eye-tracked, and touch-panel technologies are all subject to these difficulties. The remaining technology, voice recognition, can provide no list, so that its success is dependent upon the pilot's ability to access the desired symbol commands from memory while performing other tasks with competing cognitive requirements.

Table 3.1
A Summary Comparison of Control Technologies

Control Technology	Advantages	Disadvantages	Workload
Manual (HOCAC, HOTAS)	Readily available, no visual requirement	High manual workload, conflicts, limited space	Cognitive, Motor
Head-Tracked	Fast, possibly hands-free	Vibration problems, potential clutter	Cognitive, Motor, Visual
Eye-Tracked	Fast, possibly hands-free	Vibration problems, potential clutter	Cognitive, Visual
Voice Recognition	Versatile, possibly hands-free	Memory recall for commands, potential task interference	Cognitive, Motor
Touch Panel	Unlimited content, useful guidance	One hand off a/c controls, head down	Cognitive, Motor, Visual
Virtual Hand Controller	Unlimited content, control types	One hand off a/c controls, special glove	Cognitive, Motor, Visual

The final column of Table 3.1 is instructive. Each of the control technologies depends upon the pilot's expenditure of two or three types of workload resources; cognitive, motor, and visual. While it is evident that adding to the pilot's workload in order to select a symbol that may reduce his workload is less than ideal, the specific impacts of these increments in workload is difficult to determine.

We have found that the most illuminating method of evaluating the specific impacts of control technology use on mission task performance is through examination of a Task Analysis and WorkLoad (TAWL) data base (e.g., Rogers, Spiker, Bierbaum, & Dunleavy, (1996) which identifies mission segments, functions, and tasks along a timeline. For each task, the cognitive, psychomotor, visual, and auditory workloads are defined. As segments may involve the concurrent performance of several tasks, the workload ratings for all concurrent tasks are summed. Figure 3-5 presents a small sample from hundreds of pages of Mission Timeline Reports, showing the summation of workload components over three concurrent tasks. In this particular example, the total cognitive workload is 7.7, considered to be quite high, and the inclusion of any task with yet additional cognitive burdens should be avoided.

Mission Timeline Report
Segment 12: Approach (Contour)

Time	Operator	Activity	Workload COG	PSY	VIS	AUD	OWL
00:33:00	Pilot						
	Function →	Perform Hover (16)					
		Task → Maintain Obstacle Clearance (32)	1.2	2.6	1.0	0.0	4.8
	Function →	Perform External Communication (79)					
		Task → Transmit Audio Report (191)	5.3	2.2	0.0	4.3	11.8
	Function →	Monitor External Visual Scene (230)					
		Task → Monitor External Visual Scene (555)	1.2	0.0	1.0	0.0	2.2
		Workload Totals	7.7	4.8	2.0	4.3	18.8

Figure 3-5. Sample section from a TAWL mission timeline report.

While these kinds of precise, in-depth analyses are of great value in identifying the best options is specific circumstances, in attempting to select a single, most appropriate, general type of technology for symbology control it must be recognized that (a) the types of workload most likely to be experienced during use of the control are not entirely predictable and (b) the moment in the task sequence when new symbols will be selected is not known with certainty.

Thus, if pilot-initiated actions are necessary for symbology selection it would seem that rather than attempting to predict the best general-purpose technique, multiple options should be provided when possible. In this manner, at least the motor and visual workloads might be reduced by appropriate use of selection techniques. However, it may not be feasible to offer the pilot the option of multiple symbology control methods.

Finally, the cognitive workload imposed by pilot-initiated symbology changes cannot be avoided through use of any of the control technologies described above. Every one of these technologies take a toll on the pilot's cognitive resources. Whether he is using his hand, head, eye, or voice, he must still recognize the need for a symbology change, select the necessary information element from memory, identify the control action required and issue this action.

Intelligent Symbology Moding

One of the central themes of this project has been to examine the potential of an "intelligent agent" to control the flow of information via the presentation or removal of symbols from the HMD based upon the occurrence of sensed events during a mission. The importance of such an approach should not be underestimated. Its achievement eliminates every one of the disadvantages and workload components itemized in Table 3.1. All of the potential problems with taking one hand off the controls, special gloves, new buttons in limited space, need for recall of commands, additional head-down time, visual clutter from symbol selection options, and vibration effects on symbol selection are simply swept away by intelligent moding. Even more important, unlike all of the pilot initiated methods,

intelligent moding requires no psychomotor, visual, auditory, or cognitive workload.

To date, two extremes of the intelligent aid spectrum have been represented by the Comanche, and the Rotorcraft Pilot's Associate (RPA) programs. The Comanche HIDSS (Helmet Integrated Display Sight Subsystem) symbology presents all information necessary for flight, navigation, target acquisition, fire control, and degraded modes. The basic flight modes, NOE, Cruise, Approach, and IMC, are selected by pressing switches on a "touch menu" on the aircraft console. Within the NOE and Cruise modes, declutter options are available. The Comanche system has been provided with some initial symbology automation features. For example, the radar altimeter (digital and analog) displays are present in the NOE and Cruise modes when the aircraft absolute altitude is 500 feet or less AGL, and disappear above 500 feet. This is actually similar in concept to the disappearance of the Apache vertical tape and scale above 200 feet.

In addition, when Auto is selected in the Comanche, the displayed symbology set depends upon ground speed. At ground speeds greater than 40 knots, the cruise symbology set is automatically presented. At ground speeds less than 40 knots, the symbology set automatically switches to NOE. The flight path vector symbol is presented at ground speeds greater than 10 knots (except in NOE declutter). Also, if a crew member selects a weapon, the appropriate weapon symbology is added to the flight symbology. Thus, detection of the simple events such as altitude and airspeed changes and pilot weapon selections can be used to aid in symbology management.

In contrast to these simple rules, the RPA program has aimed to use intelligent aids to achieve revolutionary improvements in combat helicopter mission effectiveness by significantly reducing the cognitive workload for the crew. This reduction, in turn, requires that a knowledge-based Cognitive Decision Aiding System (CDAS) be integrated with many of the helicopter's important subsystems. The CDAS would reconfigure HMD symbology in response to external and internal events undetected by the pilot.

The CDAS element that would automatically control in-flight changes to HMD symbology is the Cockpit Information Manager (CIM). The CIM has been designed to monitor mission context and pilot actions that, in turn, support the crew with timely information and automated aids. Within the CIM itself, a Display Manager would prioritize the information needs for each crew member's tasks and select the display formats that satisfy the most important information requirements with the smallest increase in task load. As a consequence, the HMD will have many more modes and sub-modes than a traditional HMD. From a human factors standpoint, the challenge will be to ensure that any changes in symbology appearance, location, and format constitute a natural aid to the pilot's tasks and do not disrupt or disorient him in any way.

Between the halting first steps in intelligent information presentation represented by the Comanche, and the lofty, but distant, goals sought by the RPA, there lies a great range of near-term opportunity for improving symbology

management through use of intelligent systems. With the integration of aircraft systems through the 1553 bus, it is possible to sense hundreds of key events that could be used to identify the state and actions of the aircraft and its controls, and to infer the "pilot's intent" regarding activities to be performed in the immediate future. These events and inferences could form a set of "leading indicators" used to predict the most useful sets of symbols on the HMD. The initial development and evaluation of such an innovative and intelligent information presentation system for an HMD has been the central objective of this project.

Thus, instead of revising the subsets of symbols within various pre-set modes, or forcing the pilot to deal with an ever greater set of modes and symbology management tasks, an essentially "modeless" symbology management system could be developed, using an intelligent system to base symbology presentation upon the pilots immediate information requirements.

Symbology Information Organization (Moding) Strategies

The organization of information elements into sets or "modes" that are individually retrievable for the pilot's use is intended to provide groups of symbols that are suited for various phases or segments of the mission. This approach has resulted in various levels of success depending upon the quality of the information analysis employed and upon the suitability of the tasks for such division of information elements. There is clearly a trade-off between a display over-crowded with symbols and the workload of recalling the various modes and switching to them at the appropriate time.

In the case of rotorcraft HMDs, the moding solutions employed have resulted in very few changes of symbols between modes. Such a situation may well merit the moding of individual symbols by intelligent recognition of the current utility of an information element. These concepts are further explored in the following pages.

Comparing Moding of the Apache, Comanche, and ANVIS/HUD

As a background to the analysis of symbology information organization, it is illuminating to compare the three existing Army HMD symbology moding. The Apache, Comanche, and ANVIS/HUD each use quite different techniques for selection of HMD symbols. These three moding approaches are compared in the figures and tables that follow.

PNVS symbology modes, cues, and symbols. Many of the PNVS symbology elements are shown in all modes, including the: heading scale, lubber line, alternate sensor bearing, command heading, rate of climb indicator, radar altitude digital and analog indicators, skid/slip ball and lubber lines, sensor field of regard box, field of view box, cued LOS reticle and dots, airspeed readout, engine torque, and head tracker diamond. Additional cues are provided in each of the four moding operations, shown in Figure 3-6a through 3-6d.

Hover Mode

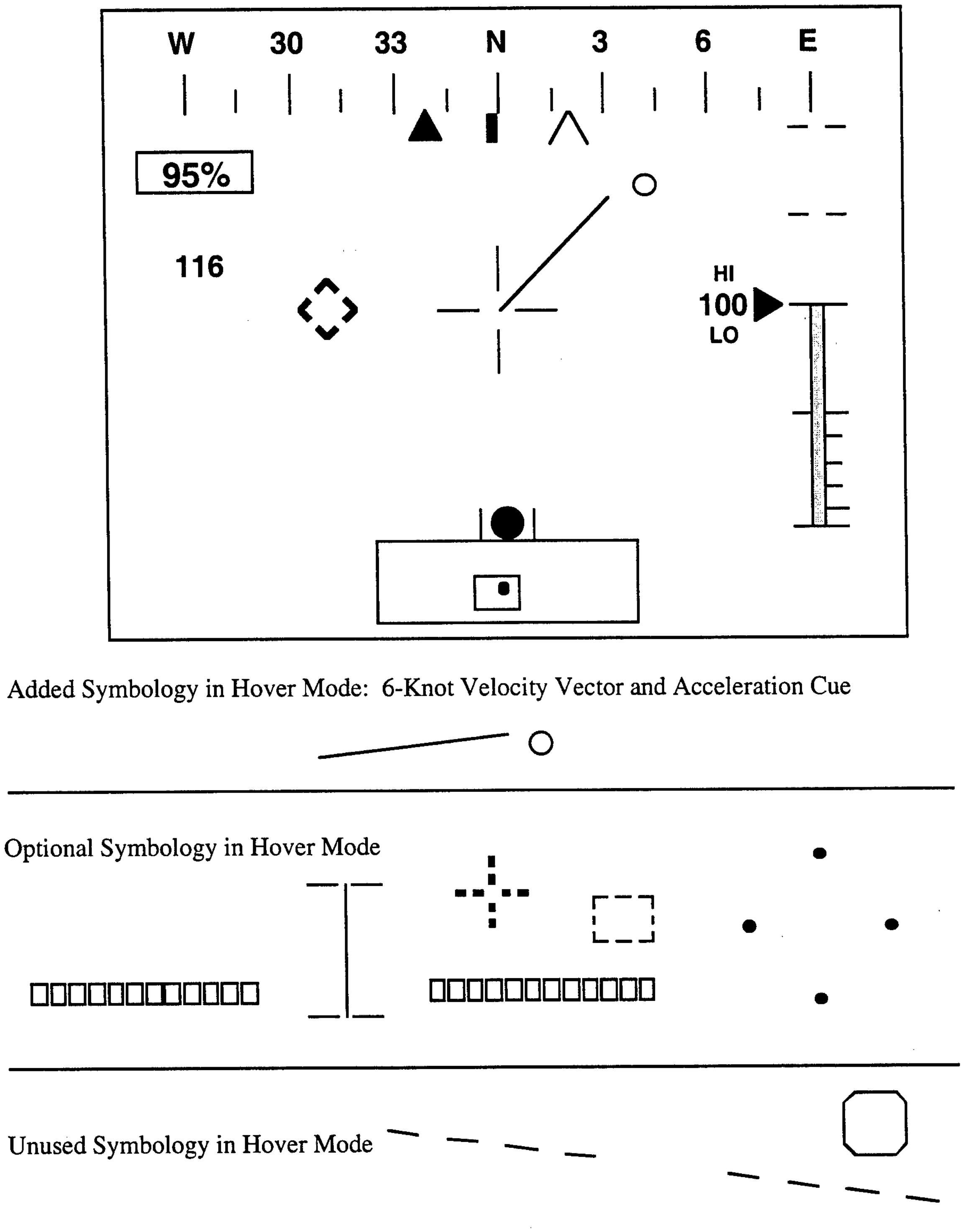
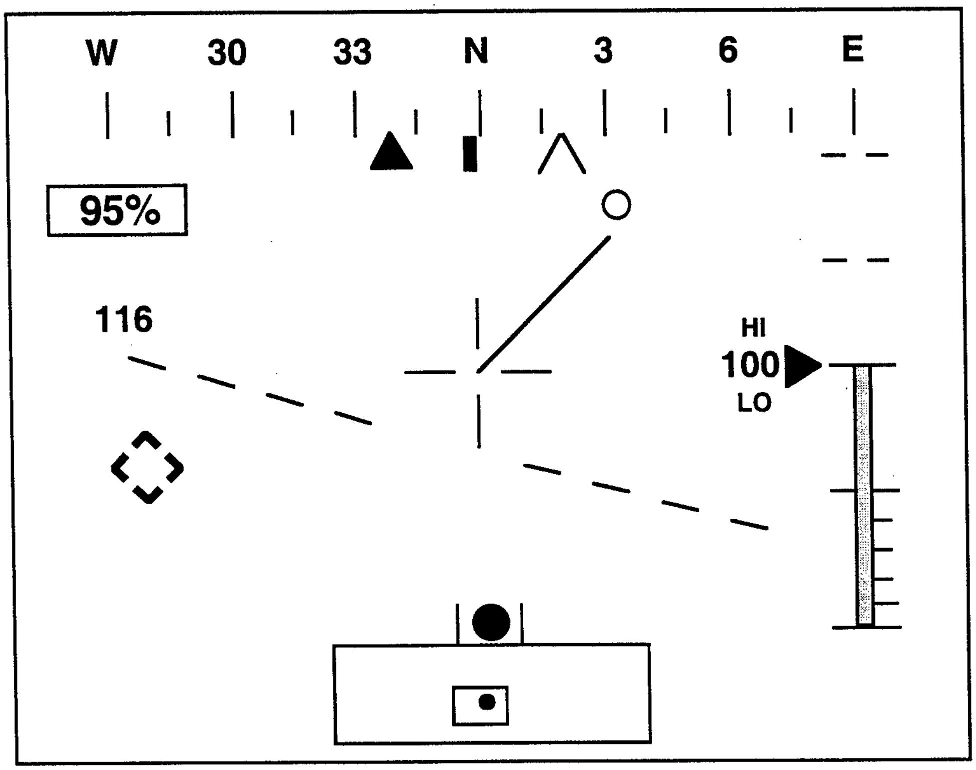


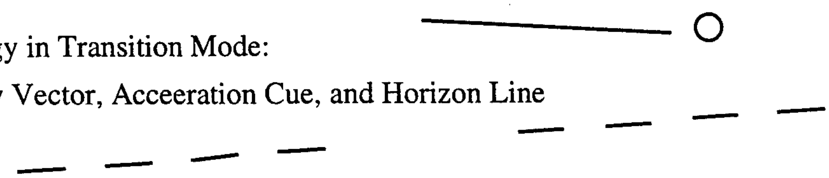
Figure 3-6a. The Hover Mode screen.

Transition Mode

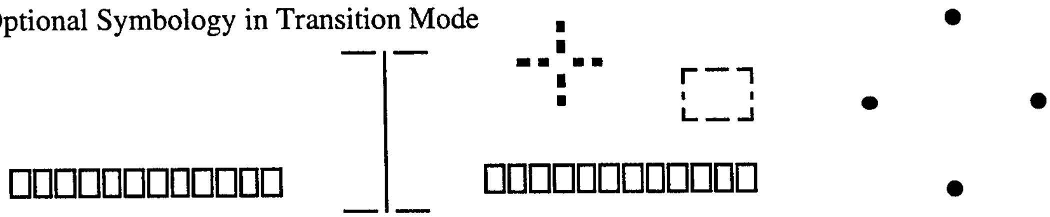


Added Symbology in Transition Mode:

60-Knot Velocity Vector, Acceeration Cue, and Horizon Line



Optional Symbology in Transition Mode



Unused Symbology in Transition Mode

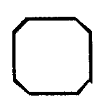


Figure 3-6b. The Transition Mode screen.

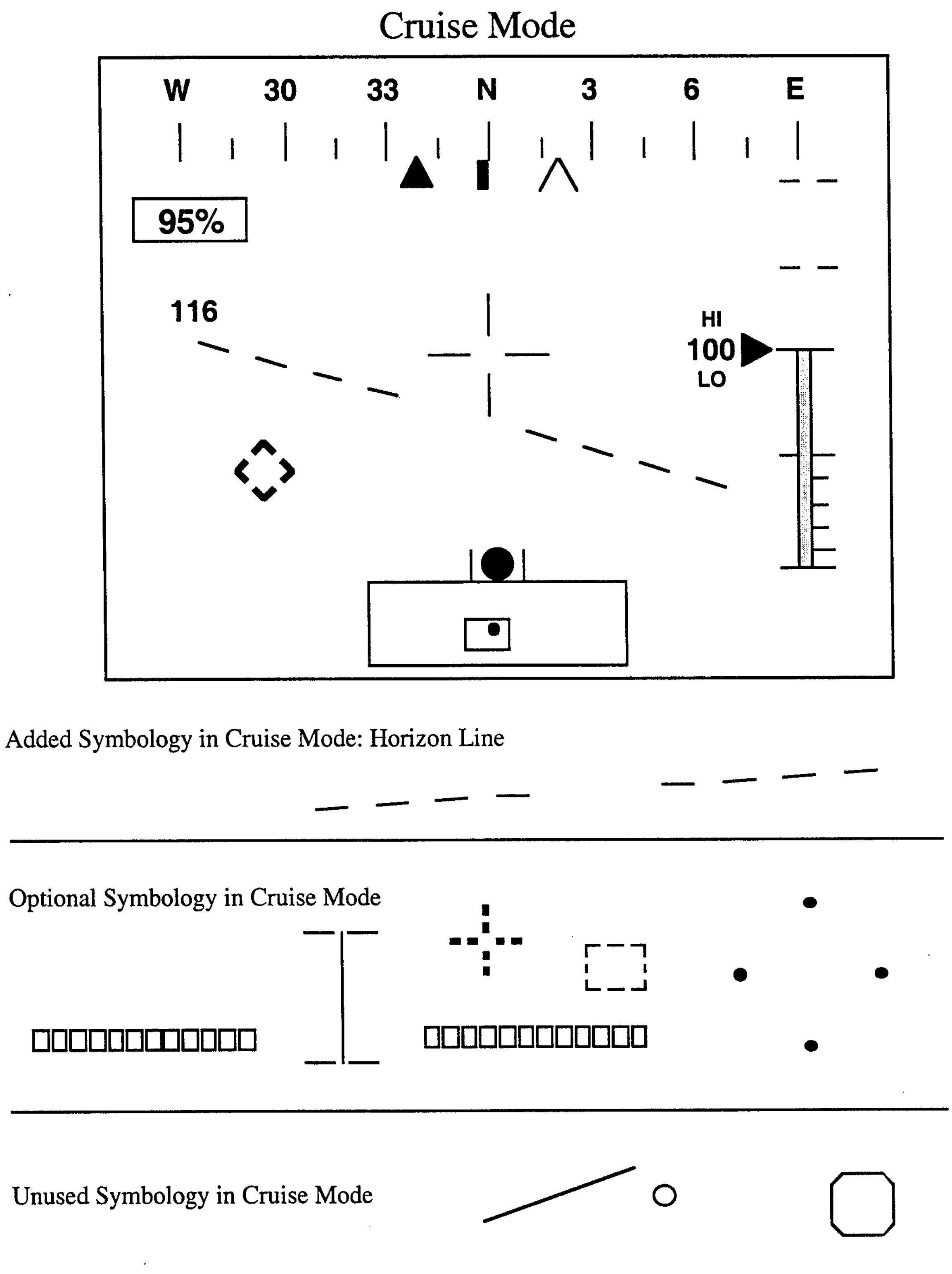
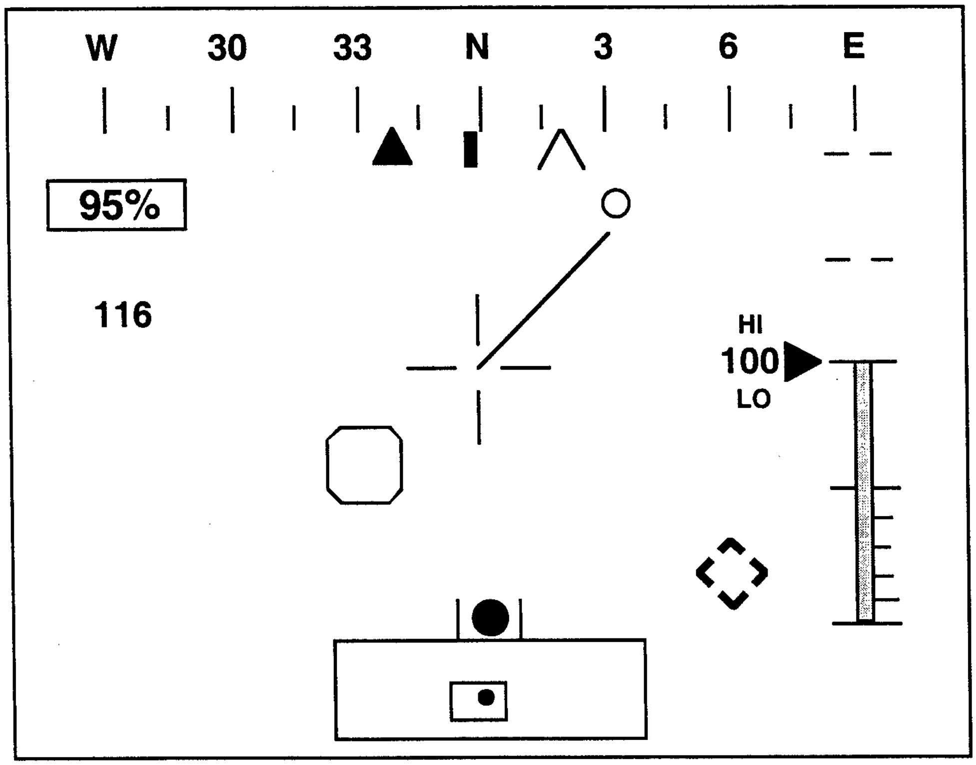
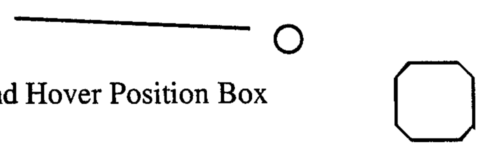


Figure 3-6c. The Cruise Mode screen.

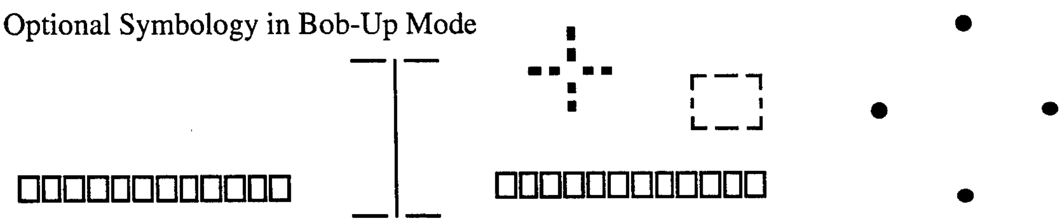
Bob-Up Mode



Added Symbology in Bob-Up Mode:
6-Knot Velocity Vector, Acceleration Cue, and Hover Position Box



Optional Symbology in Bob-Up Mode



Unused Symbology in Bob-Up Mode

Figure 3-6d. The Bob-Up Mode screen.

The apparent complexity of the Apache symbology leads less experienced observers to assume that substantial changes are made to the symbol sets when moving from one mode to another. Listing the symbols present in each mode tends to exaggerate their differences rather than their similarities. Table 3.2 clarifies the nature of the Apache moding structure. Rather than depicting all of the symbols that are presented in each mode, the symbols that are not presented are identified by the letter "N".

This table shows that the Apache moding actually changes the presentation of only four of the approximately 28 symbols: the velocity vector, acceleration cue, hover position box, and horizon line. The most frequently performed mode switch, between Hover and Transition changes only the presence of the horizon line, velocity vector, and acceleration cue.

The enablement of the other eight symbols that may potentially be presented depends not on moding selection with the thumb control, but on control selections made during weapons use. A case could be made that these eight symbols are already intelligently managed because they appear only when the pilot's intent is deduced by the system.

Table 3.2
Apache Symbology Changes from Mode Switching

AH-64 PNVS Symbology	Modes			
	CRUISE	TRANSITION	HOVER	BOB-UP
1. Position and Movement				
Line of Sight (LOS) Reticle				
Airspeed Digital Readout				
Velocity Vector	N	60 kts	6 kts	6 kts
Acceleration Cue	N			
Hover Position Box	N	N	N	
2. Attitude/Altitude				
Engine Torque Digital Readout				
Radar Altitude Digital Readout				
Radar Altitude Vertical Tape				
Radar Altitude Vertical Scale				
Radar Altitude High-Low Alerts				
Rate of Climb Indicator				
Horizon Line			N	N
Skid/Slip Ball & Lubber Lines				
3. Heading/Navigation				
Heading Scale & Lubber Line				
Command Heading				
Alternate Sensor Bearing				

Table 3.2 (Continued)
Apache Symbology Changes from Mode Switching

4. Central Cueing/Reference				
Head Tracker				
Cueing Dots	P	P	P	P
Cued LOS Reticle	P	P	P	P
5. Peripheral Cueing/Reference				
Field of Regard Box				
Field of View Box				
Cued LOS Dot				
6. Weapons Usage				
Rocket Steering Cursor	P	P	P	P
Missile Constraints Box	P	P	P	P
7. Status Displays				
Sight Status	P	P	P	P
Weapon Status	P	P	P	P
Weapon Control	P	P	P	P
Range/Range Source	P	P	P	P

N = Not used in this mode
P = Potentially used, but not controlled by mode switch

So, for the Apache, the symbology moding system is actually very simple and there are only three cases in which intelligent moding rules would need to be devised (considering only the currently existing symbol set):

(1) The Hover Position Box (On - Off)

(2) Horizon Line (On - Off)

(3) Velocity Vector/Acceleration cue (60 Kt, 6 Kt, Off)

On the other hand, many additional symbols were identified during this project that would require intelligent moding of some type.

Comanche symbology modes, cues, and symbols. Examples of the Comanche NOE and Cruise modes are shown in Figures 3-7 and 3-8 below.

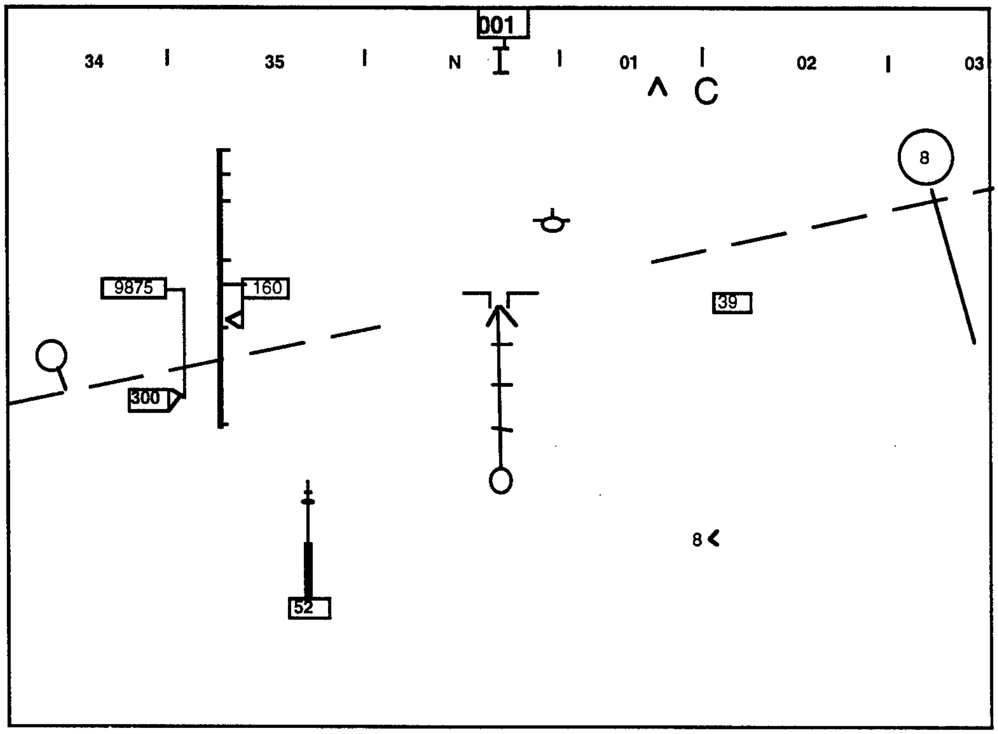


Figure 3-7. Example of the Comanche NOE Normal Mode.

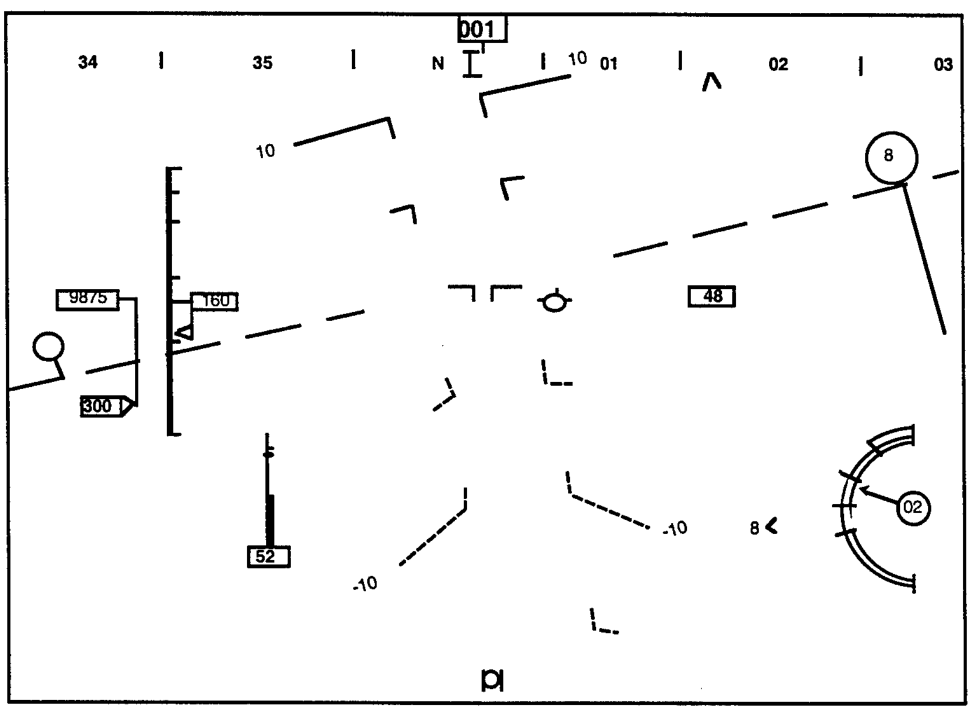


Figure 3-8. Example of the Comanche Cruise Normal Mode.

Table 3.3, below is provided to clarify the changes in the Comanche symbology resulting from selections of the NOE, Cruise, and Declutter options. The Declutter mode may be used in injunction with either the NOE or Cruise modes.

Table 3.3
Comanche Symbology Changes from Mode Switching

RAH-66 Comanche	**Modes**		
	Cruise	**NOE**	**Declutter**
1. Position and Movement			
Aircraft Symbol			
Acceleration Ball	N	0-20 kts	N
Airspeed Indicator & VNE Alert			
Flight Path Vector	>10 kts	> 10 kts	> 10 kts
Ground Velocity Symbol (High)	N	20-40 kts	N
Ground Velocity Symbol (Low)	N	0-20 kts	N
Alignment Dots for Hover Hold	N	0-40 kts	N
Hover Hold Cue	N	vel stab on	N
Maneuver Envelope Cue	C	C	C
Overspeed Envelope Cue	C	C	C
Hover Point Designator	N	command	N
2. Attitude/Altitude			
Torque Indicator (Normal)			
Torque Indicator (Split/Fail)	C	C	C
Overtorque Envelope Cue	C	C	C
Barometric Altitude Indicator		N if<500	
Radar Altitude Digital & Analog	<500 ft	<500 ft	<500 ft (dig)
Instantaneous Vertical Velocity Indicator	> 500 ft	>500 ft	
Horizon Line			
Lateral Acceleration Cue	>40 kts	>40 kts	>40 kts
Pitch Ladder		N	N
3. Heading/Navigation			
Heading Tape & Pointer			N
Heading Box (Digital)			
Current Waypoint & Distance			
Next Waypoint			
Steering Cue			N
Wind Indicator			N
4. Central Cueing/Reference			
N/A			

Table 3.3 (Continued)
Comanche Symbology Changes from Mode Switching

5. Peripheral Cueing/Reference			
Canopy Rails	C	C	C
6. Weapons Usage			
N/A			
7. Status Displays			
Overtemp Envelope Cue	C	C	C
Rotor Speed Indicator	C	C	C

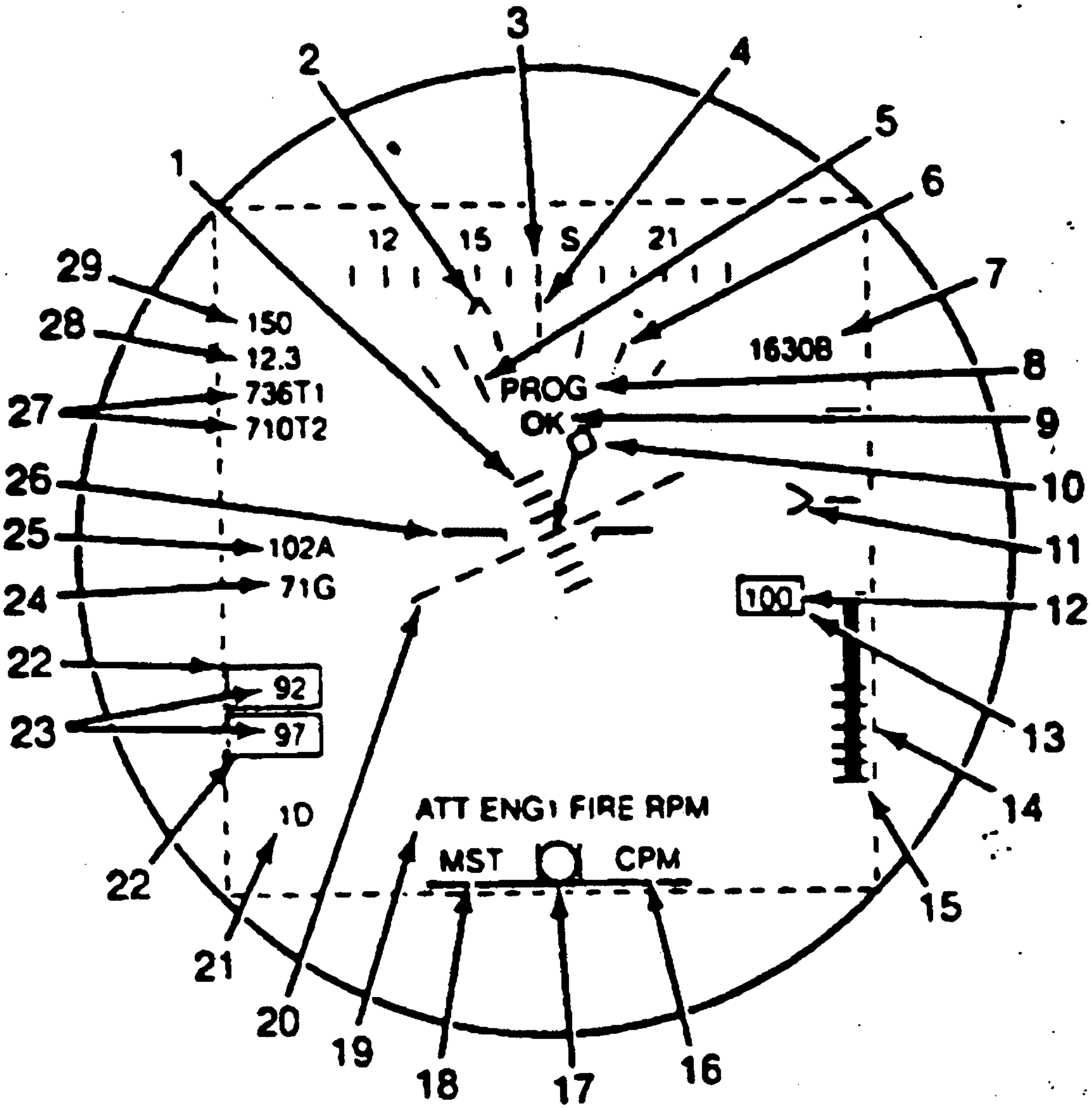
N = Not used in this mode
C = Used for special condition (not moded)

Although the Comanche symbology scheme may appear to be complex, it uses manual moding to change the presentation status of only six symbols of the approximately 29 symbols between the Cruise and the NOE mode. The Declutter mode deletes the same six plus three additional symbols. A special command is issued for the hover position designator box (depressing the boresight switch on the collective while at a hover), thus replacing the fourth (Bob-up) mode used on the Apache.

The Comanche scheme is notable for the two ways in which intelligent, automatic changes are made to the symbology set being displayed. First, when the Automatic mode is selected, the aircraft speed is used to control changes between Cruise and NOE modes. The pilot may override this control by manually selecting Cruise, NOE, or Declutter modes. Second, symbols may appear or be deleted within modes based upon airspeed or altitude changes, or in the advent of special sensed conditions, such as exceeding the aircraft envelope.

ANVIS/HUD symbology modes, cues, and symbols. The Army has recently fielded a night vision goggle system with inset flight symbology, called the ANVIS/HUD. Approximately 2600 units will be fielded, using a stroked CRT with a 34° diagonal field of view, 2:1 contrast ratio at full moon (0.005 fL), and a 32-step brightness control (0- .51 fL). An extensive survey has been performed in 1996 using 61 UH-60A/L pilots (Piccione, 1996). The pilots rated the adequacy of the device on a number of characteristics and also indicated the ways in which they programmed the eight different moding "pages" to designate which of the 29 symbols should appear when each page is selected with a thumb switch. There are apparently no reports of unit SOP for standardization of the page content.

It is interesting to note that most pilots did not use all of the modes available to them. Of the four Normal pages, 20% had programmed only one page, 49% two pages, 15% three pages, and 13% four pages. Of the four declutter pages, 30% had programmed only one page, 30% two pages, 3% 3 pages, 8% four pages, and 26% none (used the default declutter mode). Figure 3-9 shows the complete set of ANVIS/HUD symbols, and Table 3.4 shows that the only restriction to the moding arrangements are the non-deletable symbols



Symbol Reference Numbers

1. Angle of pitch scale
2. Bearing to waypoint - pointer
3. Compass reference scale
4. Aircraft heading index
5. Angle of roll - pointer
6. Angle of roll - scale
7. Barometric altitude
8. Adjust/program mode message
9. OK/Fail
10. Velocity vector
11. Rate of climb pointer
12. Radar altitude (AGL) numeric
13. Minimum altitude warning
14. Radar altitude (AGL) analog bar
15. AGL and vertical speed - scale
16. HUD fail message
17. Trim ball
18. MST,MEM,HOOK message
19. Sensor, fire. RPM warning
20. Horizon line
21. Display mode number
22. Torque limits
23. Torque - numeric
24. Ground speed
25. Indicated airspeed
26. Attitude reference indicator
27. Engine temperature
28. Distance to waypoint
29. Bearing to waypoint - numeric

Figure 3-9. Example of the symbols available on the ANVIS/HUD.

Table 3.4
ANVIS/HUD Symbology Changes from Mode Switching

ANVIS/HUD	Normal Pages	Declutter Pages
1. Position and Movement		
Velocity Vector		
Ground Speed		
Indicated Airspeed		ND
2. Attitude/Altitude		
Torque Numeric & Limits Box		ND
Radar Altitude (AGL) Numeric		
Radar Altitude (AGL) Analog Bar		
Minimum Altitude Warning		
AGL and Vertical Speed Scale		
Rate of Climb Pointer		
Horizon Line		ND
Trim Ball & Lubber Lines		ND
Barometric Altitude		ND
Attitude Reference Indicator		ND
Angle of Pitch Scale		ND
Angle of Roll Scale and Pointer		ND
3. Heading/Navigation		
Compass Reference Scale & Index		
Bearing to Waypoint Pointer		
Bearing to Waypoint Numeric		
Distance to Waypoint		
4. Central Cueing/Reference		
None		
5. Peripheral Cueing/Reference		
None		
6. Weapons Usage		
None		
7. Status Displays		
Adjust/Program Mode Message	ND	ND
OK/Fail	ND	ND
HUD Fail Message	ND	ND
MST, MEM, HOOK Message	ND	ND
Sensor, Fire, RPM Warning	ND	ND
Display Mode Number	ND	ND
Engine Temperature		

ND = Not Deletable
Otherwise, moding of 4 Normal and 4 Declutter pages is programmed by pilot.

The decision of most pilots to program no more than two or three pages is not particularly surprising since it would probably be quite difficult to remember the contents of eight different pages. The memory recall burden is worsened somewhat by the disappearance of the display mode advisory label a few seconds after the mode is selected. After this brief period, relabeling can only be achieved by changing the mode and changing it back.

Studying Modelessness

Our objective was to establish the utility of an intelligent symbology management system by evaluating the capabilities of the advanced technology that are available to provide critical information in a timely manner without developing more complicated logical structures that the pilot must remember. This technology must respond both to operator input as well as to situational and system factors without producing a complex system of multiple modes that could prevent the pilot from predicting and tracking mode transitions that he himself has not initiated.

We have come to believe that the most straightforward solutions are to reduce the number of the modes, minimize their complexity, and provide clear feedback as to their status. Providing appropriate and salient feedback is particularly critical, so that awareness of the current situation can be maintained without resorting to retrieval of system rules from the pilot's long-term memory. We chose to explore the consequences of mode reduction or elimination by analysis of the information requirements, examining each of the hundreds of information elements we have identified (e.g., airspeed, barometric altitude, current heading, etc.) to determine their potential utility in the HMD symbol set. We reviewed extensive task analysis and timeline data to establish moment-by-moment requirements and define opportunities for intelligent presentation of individual symbols, for subsequent review by Apache SMEs.

The recognition of these intelligent symbology management opportunities was partly based on our analyses of the cognitive requirements of the pilot's tasks. As an example of a cognitive requirement suggesting an intelligent symbol presentation, consider the potentially dangerous case of the confusion between the meanings of the command heading symbol in the IHADSS Bob-up mode versus the other three modes. Currently, the pilot must remember both the meaning of the command heading symbol in the Bob-up mode (an indicant of aircraft heading at mode initiation) and the mode currently in effect, in order to interpret the content of the symbol. Appropriate feedback of present mode and information element meaning could be provided simply by using a symbol that is distinctly different from the command heading caret to indicate initial heading for bob-up, thus reducing the cognitive burden on the pilot.

This example is also useful because it helps to show that the addition of individual elements of symbology either automatically, based on system or situational inputs, or the direct inputs of the pilot, can be performed effectively without necessarily leading to complexity or pilot confusions. Thus, our approach

was to first identify the individual information elements that could meaningfully be presented on the HMD, and second to determine whether they could be made to appear and disappear in an intelligent fashion. Third, we have attempted to identify the specific system, situation, or pilot-action cues that permit the derivation of rules for information element presentation or decluttering. The prior approach with several sets of symbols in different modes selected by the pilot could then be replaced by "intelligently moded" symbols individually controlled by a rule-based process. Thus, intelligently moded symbols lead to system modelessness and decreased pilot workload.

Section 4: Operational Problems and the HMD

This section of the report is intended to describe the broad range of symbols potentially presentable by the HMD. In order to do so, we have provided a brief review of Army mission management and communication tasks. This review also serves as a reminder of the extraordinary requirements made on military helicopter pilots in combat situations and the need to alleviate as much of this burden as possible.

Although task analyses and information requirements analyses are vital to identifying high-payoff symbology, their dispassionate, systematic approach tends to present a stale and lifeless impression of what is often a grueling cockpit environment. In such a high-workload environment, a primary objective of the HMD symbology designer should be to present critical data when and where it is needed. One of the key messages of this section of the report is that the "critical data" may well be mission data pertaining to positions in the real world terrain, and not just flight control information.

It is important that symbology designers keep in mind that responding to an actual tactical situation is considerably more demanding than simply flying the aircraft, viewing sensor data, and operating various systems. With little warning and with great urgency, the speed and flexibility of attack and scout helicopters can be called upon to rapidly perform diverse operations such as:

- Concentrate, disperse, or redeploy to extend the area of influence.
- React to tactical opportunities and necessities.
- Conduct exploitation and pursuit operations.
- Place forces at tactically decisive points in the battle area.
- React to threats in friendly rear areas.
- Secure and defend key terrain or deep objectives.
- Bypass enemy positions and achieve surprise.
- Conduct fast-paced operations over extended distances.

Army Aviation Mission Management

In identifying the types of shortcomings military helicopter pilots routinely face in operational settings, it becomes apparent that the most pervasive problems pertain to the quality of the *information* provided to the pilot for conduct of his combat data handling, or "mission management" tasks. Although basic capability enhancements such as in aircraft speed or weapon accuracy are often suggested to ease the pilots burden, most of the workload problems of combat operations are imposed by the enormous demands of the mission management functions. These operational problems include difficulties in both information acquisition and information interpretation.

To illustrate the nature of the mission management functions, it is useful to consider the typical roles of the attack helicopter company commander who:

(1) Receives the mission from the commander or the S3 (ATKHB or ground unit)
(2) Provides detailed planning guidance to crews of company helicopters
(3) Coordinates with the ground unit operating in the battle area
(4) Selects primary and subsequent battle positions (BPs) for attack helicopters
(5) Plans routes to holding areas (HAs) and BPs
(6) Coordinates indirect fire support and close air support (CAS)
(7) Arranges joint air attack team (JAAT) operations
(8) Controls attack helicopter fire in BPs
(9) Keeps his battalion commander continually informed of the situation
(10) Plans for and provides local security for attack helicopters
(11) Briefs the incoming ATKHC commander during relief-on-station operations
(12) Maneuvers aircraft to FARPs
(13) Directs rearming and refueling operations
(14) Conducts detailed debriefings
(15) Prepares for the next mission

During prior Anacapa studies of Army aviation roles and responsibilities, it has become clear that there is a general consensus among Army aviators that the attack helicopter company (ATKHC) company commander is "the busiest crew member on the battlefield." Nevertheless, similarly demanding types of mission management functions are performed by the subordinate attack team leaders and to some degree by all attack and reconnaissance helicopter pilots.

There are other types of high-workload activities that are best represented by the armed reconnaissance mission, and planned by the air cavalry troop (ACT) commander, whose overall list of responsibilities is similar to that of the ATKHC commander. Furthermore, the ACT commander is expected to be extremely flexible in planning and management of assigned missions while airborne and in gathering and transmitting situation data for use in the continuous planning and management processes.

Because the primary mission of the air cavalry is reconnaissance, cavalry units are more likely than other aviation units to fly in areas where the tactical situation is unknown or unclear. Thus, although air cavalry unit leaders attempt a thorough map study before flight, they may be given little information regarding the enemy situation and must concentrate on terrain analysis and the potential for enemy movements. Fight route study and selection is a never-ending activity for air cavalry aviators because their mission seldom requires that they select a "best" route, but instead that they seek out enemy activity on all potential routes and areas.

The Evolving Implications of Mission Management

Military helicopters are best employed in combined arms tactics that require surprise, flexibility, mobility, speed, and rapid shifting or concentration of combat power. These capabilities are enjoyed to the same degree by no other forces, and enable the commander to extend the depth and width of the battlefield, and to gain and maintain the initiative. These tactics and capabilities, however, lead directly to a requirement for rapid mission management activities. It is imperative that mission management activities be conducted quickly and accurately in order to ensure that the speed and flexibility of Army aviation units can be invoked to take advantage of momentary opportunities in the tactical situation.

Furthermore, given the large geographical area in which military helicopters may operate, a great deal of precious time is consumed if company and troop commanders must return to a tactical operations center (TOC) to confer with the commander and staff officers before commencing a new mission. Thus, it is clear that aviators will often be required to perform mission management in the helicopter cockpit—either in a concealed position on the ground, or while enroute to the new mission location.

It is also important to recognize that mission management is a continuous, rather than an intermittent, task. In order to simplify the complex management process for training purposes, field manuals tend to emphasize the development of operations orders (OPORDs) through face-to-face planning sessions, and to describe the distribution of paper copies of operations orders along with various map overlays.

What is missing from these characterizations is that once the operations have begun, the planning efforts do not cease, but proceed continuously. Situation reports describing the shifting battlefield situation, and fragmentary orders (FRAGOs) issued to adjust the actions of the friendly forces are frequently transmitted from, and received in, helicopter cockpits. To this extent, on-board mission management has already become one of the military helicopter pilot's required functions.

The following subsections of the report describe (a) the special operational problems currently experienced in acquiring timely tactical information, (b) the nature of the requirements for the flow of tactical operation, and (c) the difficulties in extracting or applying this information from current materials. Following these descriptive examples are some potential applications of advanced communication, map, and HMD systems to overcome these shortcomings.

An Overview of Communication Requirements

The rapidity with which Army aviation operates, and the great distances over which it may extend its resources, require that special attention be given to the communication systems that enable command and control of these operations. It is absolutely imperative that such systems function quickly and effectively in order to ensure that the speed and flexibility of Army aviation units can be invoked in time to take advantage of momentary opportunities in the tactical situation.

Effective mission management is dependent upon the availability of current tactical information. Maintaining the flow of tactical information is especially difficult for Army aviation units because of the units' large areas of responsibility, rapid-response requirements, and the wide variety of combat roles they may be fulfilling.

The arteries and veins of the tactical information distribution system are its orders and reports. Processed information is carried downward through the echelons by means of orders, and raw battlefield information is passed upward by means of reports. The processed information passed downward is an analysis of battlefield information from many sources, integrated to provide a relatively complete picture of the strength, intent, and location of enemy forces, as well as the locations and planned actions of friendly units.

In contrast, the battlefield information passed upwards through echelons is relatively unprocessed data consisting primarily of spot reports of observed enemy activity and situation reports describing circumstances on the battlefield. Report data are not integrated, but have the advantage of being the most current available.

Orders. One of the major functions of the company commander is that of receiving and interpreting combat orders—warning orders, operation orders (OPORDs), and fragmentary orders (FRAGOs). The OPORD format, which is the same at every echelon, is composed of five paragraphs: (1) situation, (2) mission, (3) execution, (4) service support, and (5) command and signal. A full, written OPORD at battalion level may extend to 20 typed pages or longer, and is usually accompanied by a series of annexes such as the following:

- Intelligence
- Operations Overlay
- Air Movement
- Air Space Management
- Air Defense
- Fire Support
- Operations Schedule
- Operations Security
- Service Support (Logistics)
- Communications-Electronics

Only one of these ten annexes is described as an overlay, but in fact each annex may have a series of appendices that include overlays. For example, the air movement annex will normally include one or more overlays (sometimes for use with different map scales) including air corridor information such as shown in Figure 4-1. The fire support annex will be accompanied by a preplanned target overlay such as shown in Figure 4-2, to simplify calling fire upon observed enemy activity.

In addition to the point targets of the preplanned target overlay, a number of other graphics may be used to restrict or control fires. Figure 4-3 shows examples of a fire support coordination line, a coordinated fire line, a restricted fire line, a free-fire area, a no-fire area, and a restricted fire area. Even from these simple examples, it is evident that the shapes of the lines and areas typically are not possible to describe by a voice or text messages.

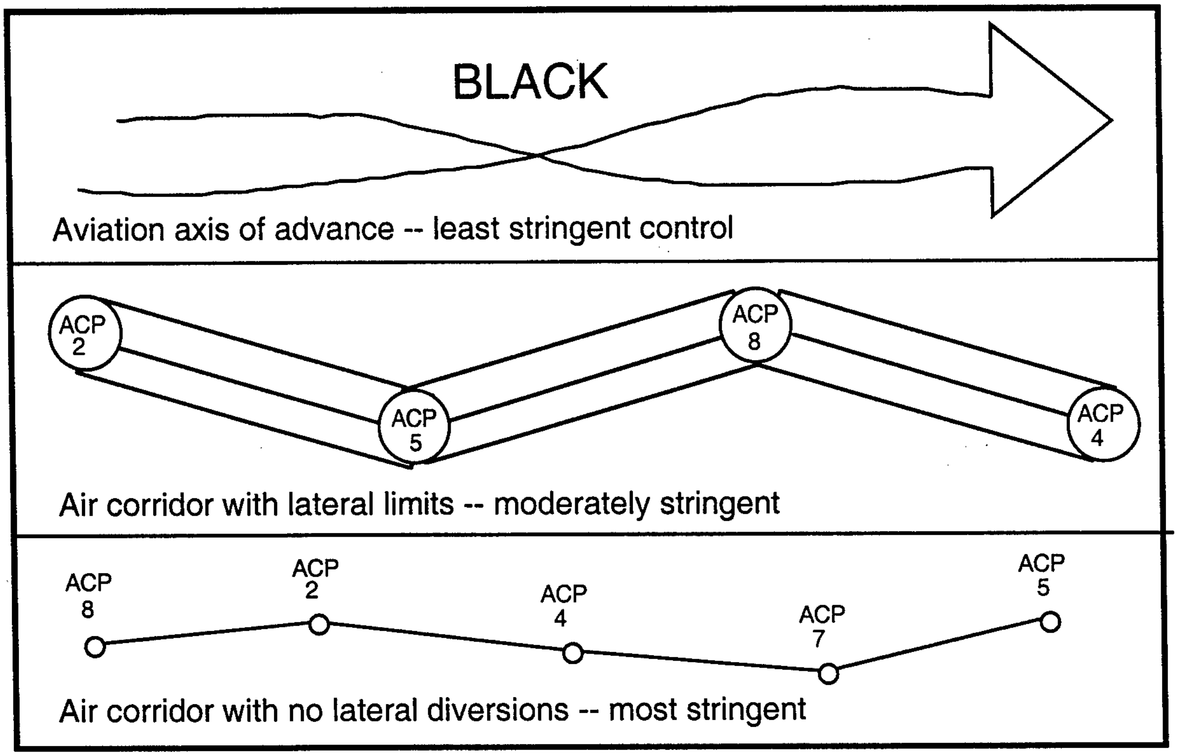


Figure 4-1. Three methods of indicating air corridors on a tactical overlay.

The fire support annex will almost always include a preplanned target overlay, as shown in Figure 4-2.

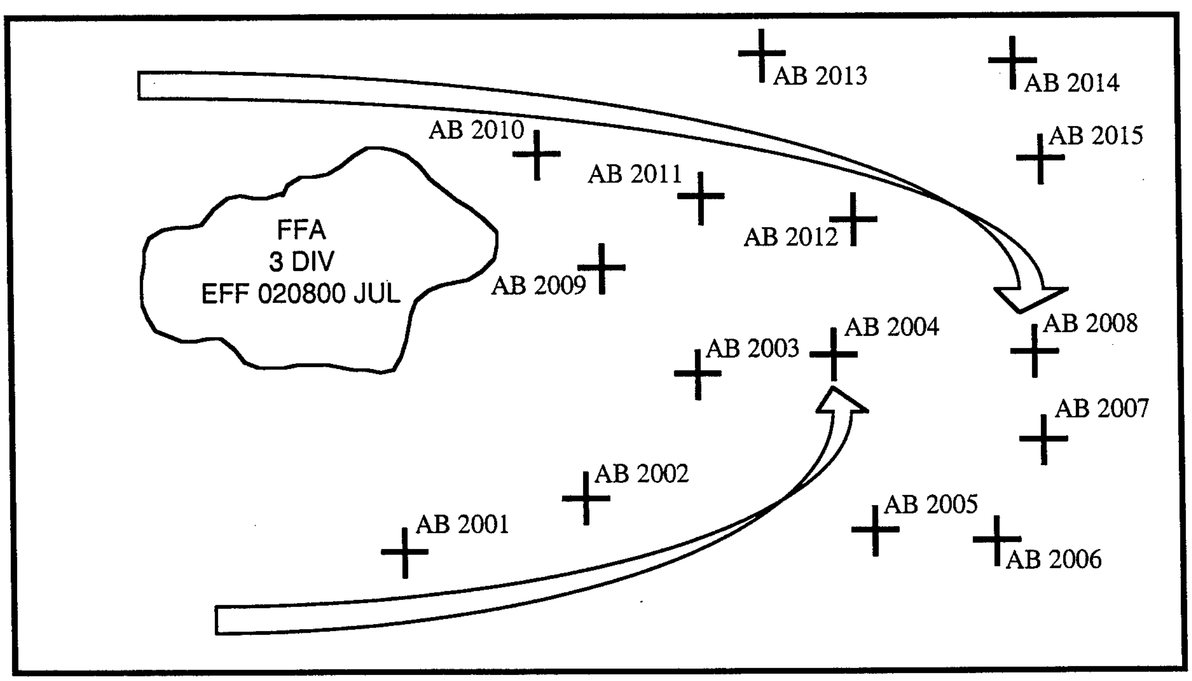


Figure 4-2. A simplified example of a preplanned target overlay.

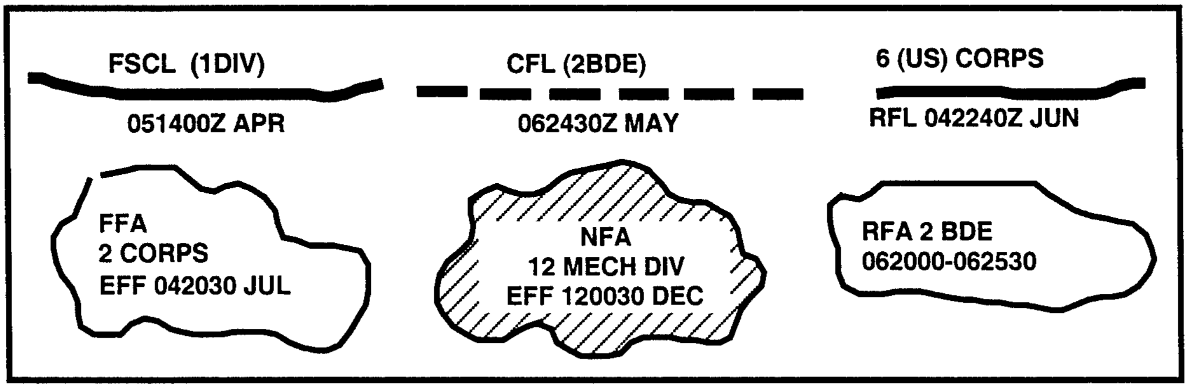


Figure 4-3. Samples of graphics used to restrict or control fire.

In addition, the intelligence, air movement, air space management, air defense, logistics and communications-electronics annexes often include map overlays. The reason map overlays are so frequently used in conjunction with orders is that an enormous amount of spatial/geographic information must be conveyed in order to conduct operations.

In order to control the various elements under his command, the attack helicopter company commander would draw his own overlay for distribution to his subordinates, carefully illustrating his concept of the operation, boundaries, phase lines, hazards to flight, ACPs, HAs, BPs, and EAs. An example of such an overlay, drawn by a SME during an Anacapa knowledge acquisition session, is shown in Figure 4-4. This overlay is intended for use on a 1:50,000-scale map. Thus, one centimeter equals 500 meters and one inch equals 1389 yards.

There are several important points to be recognized from this brief discussion of operations orders. First, it is clear that graphics are used in operations orders because they most effectively and efficiently convey extensive and critical battlefield information. Second, operations orders, because of their length and complexity, would almost never be transmitted over the radio. Third, when the tactical situation does not permit face-to-face briefings (and the distribution of operations orders, annexes, and overlays), but instead requires the use of oral FRAGOs over the radio, there is a very high probability of encountering difficulties in communicating the critical spatial/geographic information.

Reports. Just as the commander must be able to disseminate orders without delay or confusion, so must he be able to receive continuous, reliable, and current combat information about the friendly and enemy situation if he is to win the battle. The spot report is used to convey information about the enemy and his operations and is ordered by the acronym "salute," for: size, activity, location, unit, time, and equipment. A spot report is as brief as possible, as in: "Ten T-62 tanks moving south grid Sierra Tango four one six two three seven at one four two zero zulu."

The portion of the report stating "grid Sierra Tango four one six two three seven" is the geographic position of the tanks, expressed as in Universal Transverse Mercator

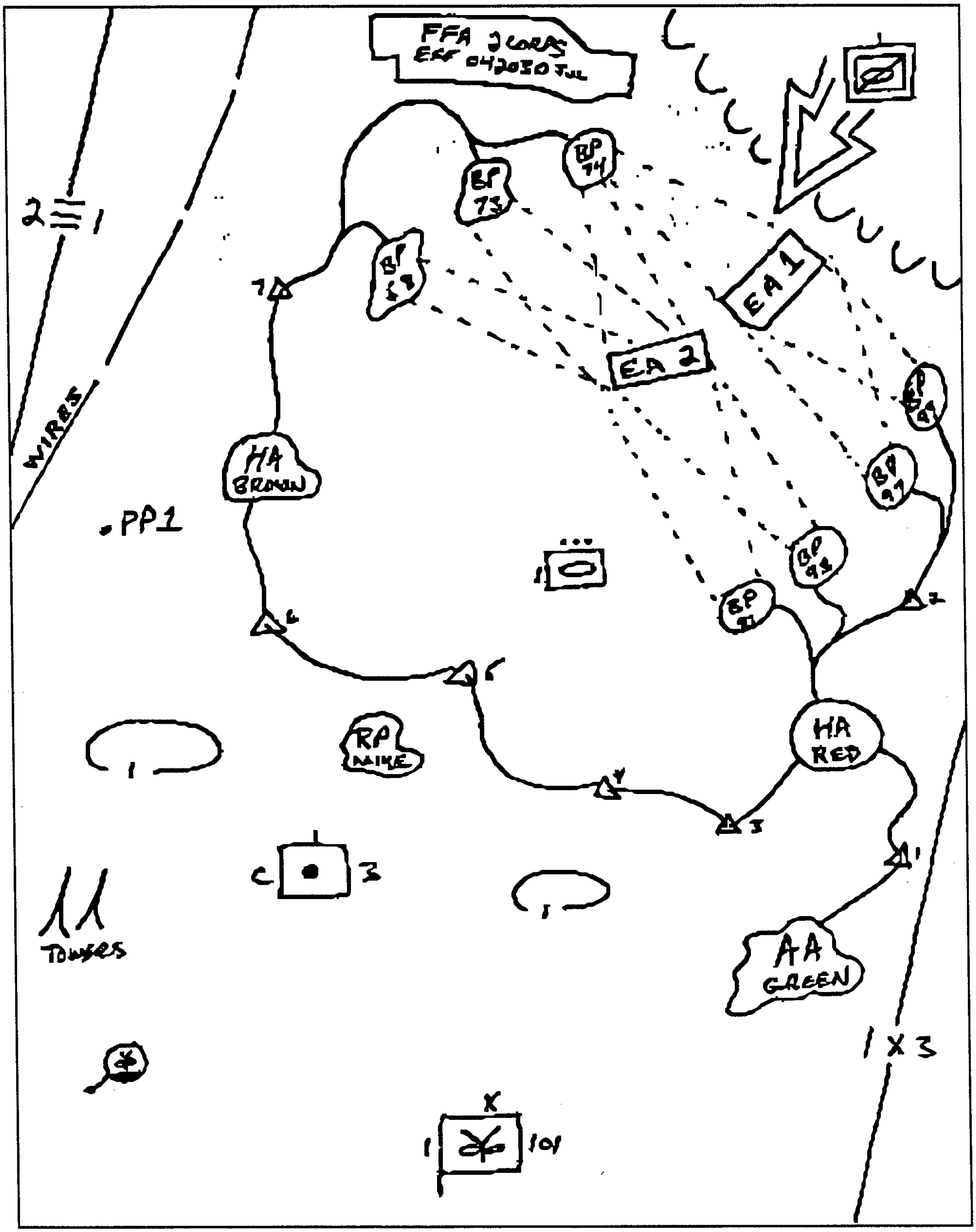


Figure 4-4. Examples of map overlay annotations used by an attack helicopter company.

(UTM) grid coordinates. Although the UTM grid system permits location of a point within 10 meters, use of the system to this level of accuracy requires that a plastic coordinate scale be overlayed on the map. The recipient of the coordinates must also use the coordinate scale in order to plot the point on the map. Because the coordinate scale is unsuitable for use in flight, aviators almost never attempt to estimate positions closer than 100 meters, that is, in 6-digit grid coordinates. Even at this level of accuracy, it is commonly acknowledged that errors are made in determining the coordinates, communicating these coordinates, and in applying them to locate a point on the map. Of course, accurate coordinate identification is useless if the pilot has mistakenly identified a landform on the map as representing one he sees in the real world.

When battle damage assessments (BDAs) follow spot reports, additional spatial/geographic data are not required unless the speed and direction of escaped enemy vehicles is transmitted. Spot reports and BDAs are used primarily at lower echelons, such as between the company commander and the battalion S-3.

Situation reports are used at all echelons, and are more extensive than spot reports. They may provide more complex geographical data, such as the movement and changing shape of an area of engagement, changes in the FLOT, and so forth. Situation reports are especially important when the situation is not developing as anticipated during planning, as in the cases of unexpected enemy troops or under-predicted speed of movement. In such cases, the information must be relayed to the S3s as quickly and accurately as possible for use by the commanders.

Problems of Communicating Required Spatial/Geographic Data

Anacapa interviews with key command and staff officers at the 101st Division (Rogers & Spiker, 1987) have revealed that there are often problems in rapidly sharing tactical data with all of those who need them. Many of the information elements that must be transmitted are spatial and geographic, such as planned routes or free-fire areas. When possible, these spatial/geographic data are obtained by tracing map overlays at the TOC. One problem in hand-tracing situation maps is that errors of omission and commission begin to creep into the data, and with time pressures, data such as logistics information, adjacent units, deep enemy forces, and friendly artillery locations may be knowingly omitted, only to be needed later.

Time Delays. Time delays, however, are a greater problem. Because of the current delays in getting tactical information to the supported unit, the time taken in posting the information to the unit situation map, the time needed by the messenger to trace the map, and the flight time returning to the TOC, the tactical information received by the BC could be several hours old. Given the fluidity of the battlefield situation, tactical data this old could be misleading, and could significantly diminish the ability of the aviation unit to effectively take advantage of the speed and flexibility of its assets. As stated previously, Army aviation is best employed in tactics that require surprise, speed, and rapid shifting or concentration of combat power. Such tactics are impossible without fresh situation data.

Thus, it is clear that transmission of situation data is required. A great deal of time is lost if the company commander is forced to periodically send messengers to the TOC to copy the situation map overlays. In addition, returning to the TOC may be impractical or impossible within the time constraints of the mission, and the information must be exchanged by voice radio. Our prior interviews with subject-matter experts at the 101st Division confirmed that these problems have already been experienced in tactical exercises.

Even when voice radio transmissions are not degraded due to large distances or jamming, the exchange of spatial/geographic data is difficult. Transmission of six- or eight-digit UTM grid coordinates permits the exchange of some positional information, but this approach is slow, subject to frequent errors, and inefficient in describing curved lines or area boundaries. Such complex spatial/geographic data as current friendly and enemy situation, scheme of maneuver, fire support, air routes and corridors, phase lines, boundaries, and other tactical data are very difficult to describe by voice radio transmission.

The results of these problems are reflected in a frequent inability to share information on the positions of friendly and enemy units on the battlefield, as well as in problems getting specific tactical information items to the key players who need them.

The potential difficulties in communicating the spatial/geographic information critical to effective orders are especially important because it is anticipated that in future battles there will be limited opportunities for briefings and distribution of paper orders and map overlays. Instead, the oral FRAGO will be the rule rather than the exception, and commanders can expect to receive mission change orders without the benefit of acetate overlays describing the current friendly and enemy situation, scheme of maneuver, fire support, air routes and corridors, phase lines, boundaries and other tactical data.

Requirements for Continuous Planning. The nature of the communications problems described here are not typically made evident in Army field manuals and training circulars because these sources tend to emphasize the development of operations orders through face-to-face planning sessions, and the distribution of paper copies of OPORDS along with various map overlays. In reality, once the operations have begun, the planning efforts do not cease, but proceed continuously.

Continuous planning, however, often precludes both the use of face-to-face consultations and the distribution of tactical data in the form of acetate or paper map overlays. Instead, radio transmissions or messengers must be used to share tactical data and issue FRAGOs. Because the contents of a FRAGO may include any of the data used in an OPORD, it is a certainty that overlay-related information is needed in these communications, and it cannot often wait until the next face-to-face encounter at the TOC.

During an operation, when the S3 and the BC are within secure voice radio range, they attempt to maintain situation overlays by sending six-digit grid coordinates, but this is acknowledged to be a slow and crude method of transmitting data. The commu-

nications electronics operating instructions (CEOI) message coding, authentication tables, and terrain index reference system coding described in Army field manuals are simply "time prohibitive" and too error-prone, and are never actually used.

Large areas of operation. The area of operations for the attack helicopter battalion is very large—essentially the same as that of the division. The attack helicopter companies must be ready to move anywhere in this area, crossing brigade boundaries or performing deep attacks across the FLOT, with only minimal advance notice. It follows that each of the company commanders needs to be furnished with the most comprehensive and current tactical overlay data available before moving to the new area of operations. Unfortunately, this is not currently the case. Furthermore, attempting to obtain data by moving to an unfamiliar TOC area without a clear definition of enroute dangers from enemy (as well as friendly) activities can be risky.

Preplanned control measures such as phase lines and checkpoints become very important in command and control during the battle because they permit the transmission of spatial-geographic data that are understood by both communicators. Unfortunately, given such large areas of operations it is impossible to foresee all of the possible zones in which aviation units may operate, especially since the enemy actions are not completely predictable.

As a result of these uncertainties, changes in the mission transmitted by FRAGOs may often place aviation units in areas for which preplanned control measures are unavailable or insufficient. These situations are a natural outcome of the rapid redeployment advantages of Army aviation, and should be expected to be a frequent occurrence in future conflicts. As a result, the BC or his messenger must either fly to the ground maneuver TOC to examine the local situation map and trace the pertinent overlays or attempt to overcome the clear deficiencies of voice transmission of spatial data. An ability to transmit new phase lines, sectors, fire control data, air corridors, routes, holding areas, and so forth will become not only a convenience, but a necessity for conduct of fast-paced operations over extended distances.

Emerging Solutions to Mission Management Problems

In future rotorcraft, innovative technology will be incorporated to vastly improve mission-management efficiency. There are three broad technology categories that address the special operational problems described in this section of the report. They include better tactical communication systems to ensure the necessary data is available; advanced digital map systems to provide more compatible views of the terrain and intervisibility computations for determining masking; and HMD systems and symbology to facilitate the integration of the extensive spatial/geographic data in the most intuitive and helpful manner. The following pages present brief summaries of the new communications and digital map contributions, followed by a more extensive description of the HMD contributions.

Communications Solutions to Mission Management Problems. In the near future, powerful improvements in radio systems and data link capabilities will be implemented permitting the storage and transmission of extensive amounts of tactical

information. These systems will permit secure, jam-resistant communications that will not only reduce cockpit workload, but will eliminate many of the current requirements for flights to the TOC to deliver combat reports or to trace the situation overlays. Furthermore, the new systems will permit "databurst" transmissions among aircraft to share tactical data without recourse to voice transmissions or actual landings for conferences over paper maps and acetate overlays.

For example, the RAH-66 Comanche will support data linking through implementation of a high-density data transfer module that will permit the storage and exchange of huge amounts of mission-planning data, both on the ground and in the air. The Data Transfer System on the Comanche will provide automatic loading of such data bases as terrain, CEOI, meteorological, and C^3I. The Comanche will also receive a Level III integration of the 1553B data bus that will support data transmission at rates 50 times greater than the current B version. This has the potential to permit fusion of EO sensors, RF sensor inputs, aided target recognition, automatic sector search for improved target acquisition, and inflight reconfiguration. It also supports further modularization and miniaturization of avionics systems.

The improvements in tactical communications systems will permit data-bursting the required map overlay data including situation graphics, fire control data, and other geographic position information to the cockpit. In return, the pilot will be able to immediately transmit the most current battlefield report information to his commander.

The key issue is that these new capabilities will pave the way for a real-time situation awareness capability in the cockpit that is so strongly desired by aviators. For example, the data from new FAADS sensors that are designed to identify and locate enemy helicopters could be sent directly to friendly aircraft, instead of through the TOC. In a related application, targets could be rapidly passed to direct support (DS) artillery, and some safety provided by passing friendly helicopter positions at the same time.

Another example of a likely real-time situation awareness capability will be a method of avoiding enemy air defense artillery (ADA) engagement areas. Enemy ADA sensors are usually turned off and do not begin emitting until friendly helicopters get close, so there is minimal preparation time for dealing with this danger. With a real-time threat display system, the weapon positions and friendly aircraft positions can be relayed immediately to friendly artillery for a suppression decision, and to friendly helicopters for a decision to bypass or engage the sites. There is no similar capability currently available, and there is concern that in a conflict the aviation units would be, as one pilot put it, "just blundering along, marking the threat with our burning helicopters."

Digital Map Solutions to Mission Management Problems. Just as paper maps have been the focal point of planning and navigation in the past, digital maps will form the heart of most future mission-planning systems and head-down cockpit displays, integrating diverse spatial/geographic information. The use of the digital map display has some enormous advantages over paper maps, especially if digital terrain elevation data is provided. In the mission-planning setting, the digital map display facilitates

terrain analysis, waypoint and route data handling, and special computations, and offers a comprehensive and comprehensible method of integrating important, complex spatial elements of the plan.

Digital maps are subdivided into two major categories: computer-generated maps and digitized paper maps. Computer-generated maps provide extraordinary advantages for the planner. They permit him to generate "tailored" products, such as maps in any scale with any subset of topographic features. Computer-generated maps can show the landform contours in plan or perspective view, using slope-shaded surfaces to convey a three-dimensional appearance that is extremely useful in terrain analyses. The digitized paper map, in contrast, permits use of the high-resolution data available from the huge selection of existing maps and charts. Either computer-generated maps or digitized paper maps can be augmented with intervisibility calculation displays based on terrain elevation data. The primary advantages of both types of digital maps are summarized in the following four paragraphs.

- Waypoint and Route Data Handling—The painstaking process of determining the coordinates and elevation of waypoints and other positions from paper maps can be entirely eliminated. Instead, a cursor can be positioned on the map display screen, and these data furnished instantly. When necessary, latitude and longitude can be automatically converted to UTM coordinates. The range and bearing between waypoints can then be automatically forwarded to other components of the system for time/fuel/distance calculations. The tedious annotation of paper maps can also be eliminated, with course lines and waypoint data automatically entered for display on digital maps in the cockpit.
- Terrain Analysis—The perceptual task of relating map contour lines to the expected appearance of terrain relief in the area of operations is perhaps the most difficult aspect of map interpretation. The computer-generated map can be used to present a slope-shaded, plan-view depiction of the terrain, having the appearance of a 3-dimensional relief map, thereby making the actual landform contours immediately apparent to the viewer. In a related technique, the image can be "rotated" to provide a perspective view of the terrain, familiarizing the pilot with the landforms as they would be seen during flight at any chosen altitude and heading.
- Intervisibility Computations—The digital map and its associated terrain elevation data base can be used to perform mission-planning computations of previously forbidding complexity. Masking and backdrop from known or suspected enemy positions, fields of fire from an aircraft at any given position and altitude, and other computations are made simple. Among the most critical of these computations are the threat lethality envelopes surrounding known or suspected weapon positions. Such positions are currently shown on paper maps by simple circles representing maximum weapon ranges. Yet, lethality envelopes may now be calculated to show the masking effects introduced by terrain at any selected aircraft altitudes.

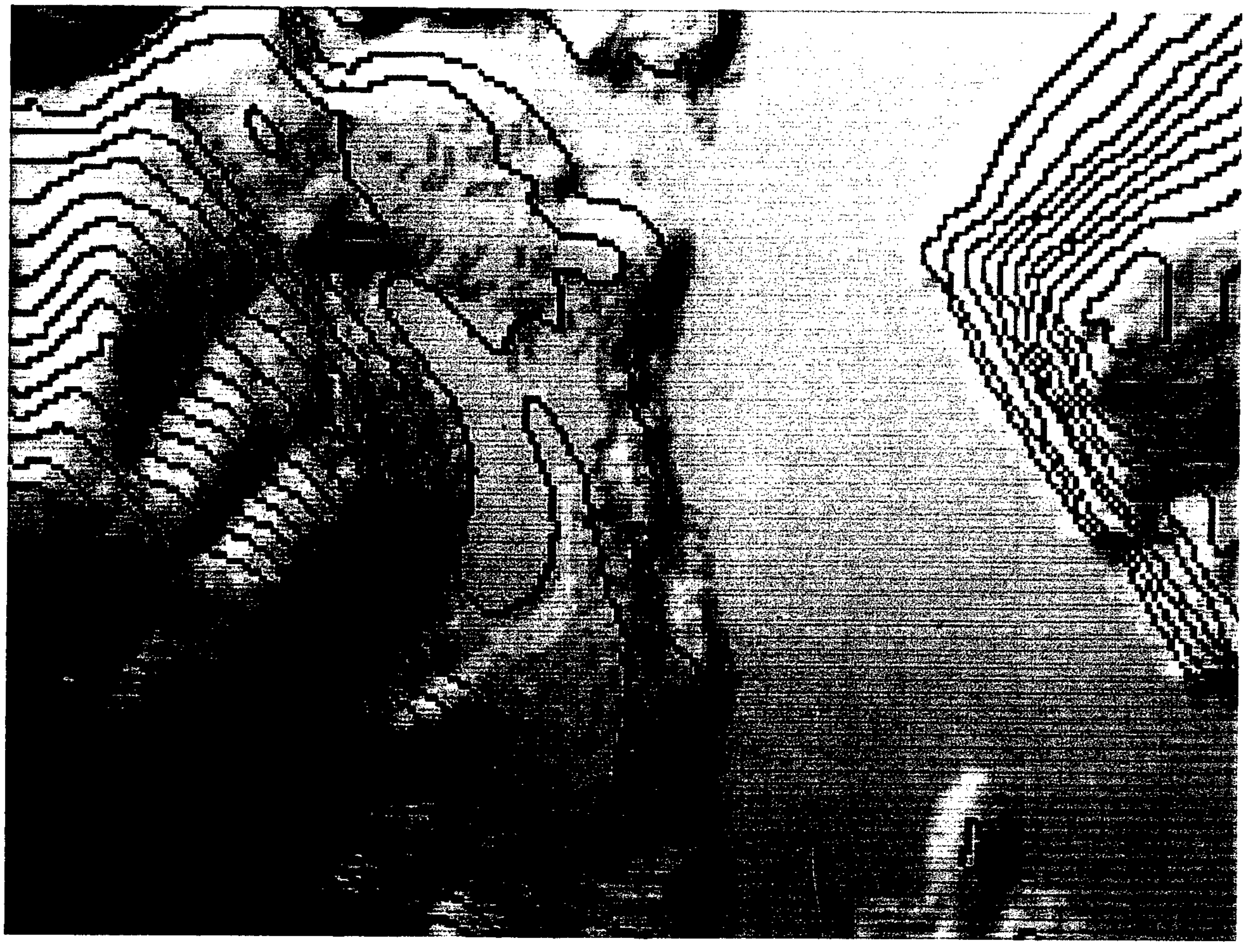


Figure 4-5. An example of a slope-shaded plan view digital map format.

Figure 4-6. An example of a digital map perspective view of terrain.

- Information Integration—The digital map offers the most direct and easily understood method of integrating the hundreds of spatial and geographic information elements dealt with during the planning process. Various sets of overlays from the intelligence, weather, operations, or other data bases may be displayed at will, or rapidly deleted to eliminate clutter and permit the underlying terrain to be examined. Special-purpose annotations may also be introduced to prepare the display for inflight use.

HMD Solutions to Mission Management Problems. Applications of HMDs in advanced rotorcraft focus on their ability to present flight symbology similar to the HUD's, reducing head-down time and eye re-focus time, and providing conformal symbology such as airfield outlines. The ability of the HMD to be used off-axis is assumed to improve the ability to search the real-world environment while still viewing critical flight data. Thus, there is a great deal of discussion about such issues as potential confusions judging aircraft attitude from observing a forward view of the horizon line while looking 90° to the left or right of the aircraft centerline.

Overlooked in this conceptualization, however, are the extraordinary opportunities to integrate mission management data in a more intuitive and informative manner than has ever before been possible. The HMD, integrated with spatial-geographic information provided through advanced communication systems and digital map devices provides a long-awaited method of bridging the gap between the real world and its traditional symbolic encodements (alpha-numeric data and map icons).

Expressed concisely, given new communication systems capable of rapid transmission of extensive graphic data and new digital map systems capable of selectively displaying all manner of head-down tactical situation graphics, HMDs can be used for presentation of any of these important information elements in the form of symbology overlaid on (conformal with) the real world or on simulated perspective views of the world generated from digital terrain elevation data.

In addition to this "augmented reality" capability, the HMD can be used not only as a display, but as an input device to the new digital maps and communications systems. By use of manual controls or head movements, the pilot can quickly "point out" positions in the real world using indicators in his HMD symbology set. He can then cause these positions to be highlighted on the maps or in the HMD views of other aircraft to give an "over-the-shoulder" immediacy to his orders and reports.

The HMD and Cognitive Workload Reduction. As an overview to the utility of the HMD in solving mission management problems, it is useful to consider the nature of the pilot's cognitive tasks in dealing with the real-world position of tactical information elements. In particular, the HMD's unique potential for enhancing the pilot's situation awareness is related to the concept of "visual momentum," a term which was originally used to describe the visual impetus or continuity a cinematographer attempts to create in film editing to establish a visual coherence across several scenes (Hochberg and Brooks, 1978). The term was later expanded by Woods (1984) to describe the features of

a system design that enhance an operator's ability to extract and integrate information across several displays.

A greater amount of visual momentum is said to help the operator to maintain a cognitive representation of the system through presentation of one display's information in the context of another. The objective is to provide "perceptual landmarks", or "anchors", to help maintain a cognitive representation of the data. Visual momentum can be viewed more broadly as an aid to transitioning between a variety of points of view and cognitive representations.

Visual momentum is especially important for military rotorcraft because of the frequent need to transition between sensor imagery, horizontal situation displays, vertical situation displays, and the out-the-window views while maintaining cognizance of the spatial relationships of among battlefield terrain, tactical features, and one's own changing position. Although little experimental work has been done to empirically explore the characteristics of a display that best provide visual momentum, it is apparent that smooth and intuitive transitioning between head-down displays, head-up displays, and the real world should be one of the major goals of an aircraft display system

In searching for opportunities to use visual momentum to enhance the cognitive integration of information on display systems, the first step is to examine categories of spatial information that are used in pilot tasks and determine whether they are currently displayed in the manner most natural for task conduct. To overcome errors and incidents in information transfer, it must be easy to integrate new data with existing information regarding the tactical situation in order for the pilot to rapidly achieve a global understanding of the situation. Research in engineering psychology (e.g., Boles & Wickens, 1987) suggests that an important characteristic that can facilitate the integration of new information with old is the similarity of the means of representing the information elements.

For example, if a pilot's display, as well as his "mental model" of the information type is visual-spatial, a new information element of this type should also be presented in the same visual-spatial manner. This approach may seem patently obvious, yet pilots often need to mentally transform information in a vocal or textual message to its visual-spatial meaning in order to integrate it into the tactical situation. With the advent of digital data-link technology, it is now possible to encode the relevant spatial data in such a manner as to facilitate its display in the most appropriate manner, or in multiple modalities, locations, and formats, if the task so warrants.

The development of advanced HMD systems has revolutionized the possibilities for the use of visual momentum as an aid to the pilot. As a result of these developments, it has become possible to ease transitions not only by adding spatial symbology to the digital map, but by placing markers on the sensor displays or on the real world terrain through the use of HMD systems.

The HMD and Augmented Reality. It is unclear how far can the visual momentum approach could be carried in designing HMD symbology. It is clear, however, that is

nearly impossible for the pilot to maintain a complete cognitive map of tactical data perfectly overlaid on the visual image of the real world. The HMD provides a potential solution to this serious problem and its uses should be carefully considered. Although the focus of HMD development previously has been on flight symbology, there are scores of tactical features that could be represented in an "augmented reality" fashion through the use of the HMD.

A "virtual reality" is an environment or "digital world" in which the participant is no longer aware of looking at a screen, but becomes "immersed" in the imaginary scene. "Augmented reality," on the other hand, involves methods by which information can be projected on the real world to aid in tasks where both the real world and the additional data are needed. Although the HMD is the ideal virtual reality display, its application in flight is that of an augmented reality system, overlaying virtual images on the real world (either through the cockpit monitor or a sensor display such as FLIR) to provide the required information. The information may be directly related but abstractly presented, such as digital readouts of speed and altitude, or it may be presented in a spatially integrated fashion (conformal) that maps onto specific points in the terrain, such as the horizon.

Augmented reality will be of enormous aid to geographic and spatial orientation. As powerful as digital map systems may be, they are not capable of integrating their information elements with the real world seen out-the-window. Instead, the pilot must perform several relatively difficult cognitive tasks in order to bring the cognitive representation of head-down symbology into accurate registration with head-up, real-world imagery.

In contrast, use of the HMD permits any of the information elements on the digital map to be presented through head-up symbology, so that the positions of these elements can immediately be located in the real world. Augmenting reality with information selected from the map display introduces visual momentum and will provide opportunities for integration of mission management information in a more natural and useful manner that has ever been achieved.

The opportunities thus provided for the pilot are extraordinary. He can follow HMD waypoint symbols along an axis of advance while other symbols warn him of areas that are dangerous due to contamination, enemy weapons, friendly free-fire areas, or flight hazards. The locations of holding areas, phase lines, passage points, rally points and battle positions can be made unmistakable. Any information element that has an identifiable position on or above the terrain can no be represented in that position in the real world instead of being restricted to map overlays viewable in head-down, plan view modes.

Not only would geographic orientation be vastly improved, but tactical situation awareness could be greatly aided by using the HMD to present tactical data such as boundaries, phase lines, engagement areas, rally points, and preplanned artillery targets on the real world terrain. Critical new information elements from real-time intelligence sources or combat reports could also be depicted in the terrain as well as the map display. A preliminary list of tactical data elements taken from Army mission

management manuals is shown in the box below. These elements are currently shown on map overlays, but could benefit from presentation by the HMD, overlaying them on the real world terrain or on computer-generated views of the terrain by the HMD system.

Enemy forces	Fire support	Movement technique or formation
Location	Planned targets	Control measures
Disposition	Preplanned CAS	Inadvertent IMC procedures
Composition	Passage points	Flight hazards
Strength	Radio transmission points	Escape and evasion pickup points
Capability	Routes of adjacent units	FARP locations
Probable course of movement	EW plan	Escape and evasion routes
Friendly forces:	Obstacle Plan	Downed aircraft pickup points
Disposition	Deception plan	Landing zones
Forward edge of the battle area (FEBA)	SEAD plan	Fire Support data
Forward line of own troops (FLOT)	Flight coordination	Target numbers
Strength	Air routes and corridors	Point targets
Course of action	Air control points	Final protective line
Battle area boundaries	Checkpoints	Linear targets
Other Army aviation OPNS in area	Communication control points	Coordinated fire line (CFL)
Location of division CP and axis of displacement	Rally points	Fire support coordination line (FSCL)
Friendly ADA positions	Assembly areas	Restrictive fire line (RFL)
Friendly CPs	Forward assembly areas	Rectangular targets
Concept of operation	Holding areas	Circular targets
Scheme of maneuver	Phase lines	Free fire areas (FFA)
Axis of advance	Delay lines	Restrictive fire areas (RFA)
Engagement areas	Passage points	No-fire areas (NFA)
	Battle positions	
	Firing positions	
	Firing sectors	
	Mode of flight, airspeed, altitude	

Figure 4-7. Information elements from map overlays for augmented reality.

Comanche conformal symbols. This extraordinarily powerful augmented reality capability has been little explored in a tactical setting, although the Comanche conformal waypoint symbols have provided at least one very good example of what can be done. The Comanche helmet integrated display and sight subsystem (HIDSS) was designed to provide information in a contact analog format, when possible. One of the goals of the Comanche design team has been to minimize "semantic distances". The semantic distance is said to be large when the pilot must think about his goal in one set of terms and translate those thought into another set of terms in order to decide upon the current status. In spatial terms, minimizing semantic distance is related to the concept of easing transitions through visual momentum.

Waypoint symbols are "earth stabilized" in the HIDSS system, and remain superimposed over their real world referent as the pilot moves his head. The current waypoint symbol appears as a circle at the top of a long pole in the earth, as shown in Figure 4-8. The pole appears to be planted in the earth at the geographical location of the current waypoint. If the waypoint is beyond the horizon, the pole extends only to the horizon. The number in the circle indicates the distance to the waypoint. The next

waypoint symbol is similar to the current waypoint except that the circle is smaller, to give an impression of greater distance.

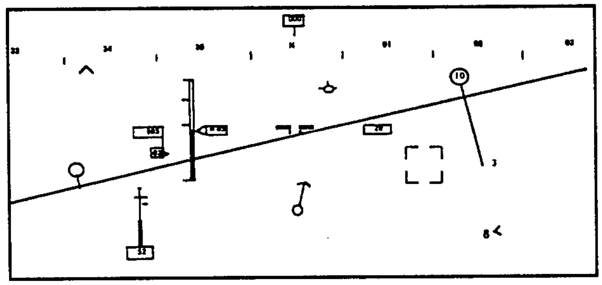


Figure 4-8. The Comanche current and next waypoint symbols (NOE-normal mode).

Thus, as the pilot flies through the terrain, he is constantly oriented by the round virtual waypoints overlaid on the real world, which correspond directly with the round waypoint symbols on the horizontal situation display (on his digital map). Thus, visual momentum is preserved by the similarity of presentation modality and formats.

The HMD and communications improvements. Although the improved communications and digital map systems will vastly increase information sharing between the TOC and the company commander, the HMD can further aid these transmissions by eliminating the difficulties and errors in translating between the real world and the map, and in position cueing within and between aircraft.

<u>Communication within the aircraft</u>. Visual cueing to positions in the terrain is presently rather clumsy in the AH-64, even though much improved over the AH-1 Cobra aircraft. The procedure now used in the AH-64A to cue the pilot to a position in the terrain is as follows:

(1) If the positions are preplanned and entered in the FCC, the CPG will select them with the Data Entry Keyboard (DEK) and slave the TADS to them.

(2) To point out a position to the pilot that is not pre-entered in the FCC, the CPG must enter the 8-digit grid coordinates in the DEK or find the position by visual search and fire the laser to obtain coordinates. He then slaves the TADS to the position.

(3) The pilot can then set the ACQ SEL control to "CPG" so that the cued LOS reticle is the azimuth/elevation of the coordinate's location in the terrain, and use the cued LOS dots to acquire the cued LOS reticle. This cue, of course, is temporary, lasting only until the TADS LOS is redirected. It is at this point that the pilot is truly able to "look where the CPG is looking."

While this cueing procedure is effective, it demands that the CPG and his TADS be fully dedicated to support maintaining the pilot's situation awareness. In fact, the TADS is primarily in use for target acquisition and the CPG is heavily burdened with navigation, communication, and weapons handling tasks.

When a digital map becomes available in the cockpit, the pilot's designation of any map position could result in the appearance of a "pointer" symbol identifying that

position in the real-world terrain. In a similar manner, the pilot's LOS could be used to identify a feature in the real world and enter a symbol on the digital map for immediate or later reference. Thus, the difficult problems of map-terrain correlation would be overcome. Even in the near term, without a digital map, it should be possible for the pilot to select any preplanned position for "virtual cueing," by the HMD without involving the TADS or the CPG, as long as the head tracker and navigation system accuracy are improved.

Communication between aircraft. One of the HMD's most important new capabilities is its ability to point out terrain or tactical features to pilots in nearby aircraft. There are currently three methods for performing target hand-offs: voice with directions, voice with coordinates, and laser tracking. For each method, a price is paid in terms of performance time, potential detection by the enemy, or both.

Target hand-off could be improved with a "passive ranging" capability made possible through greatly improved head-tracker accuracy and the incorporation of digital terrain elevation data bases. The computation method is depicted in Figure 4-9, below and is performed by computing the intercept of the pilot's line of sight with the terrain data base. The computed coordinates could then be sent verbally, or by "databurst" in which a conformal target marker is presented in the recipient's HMD symbology.

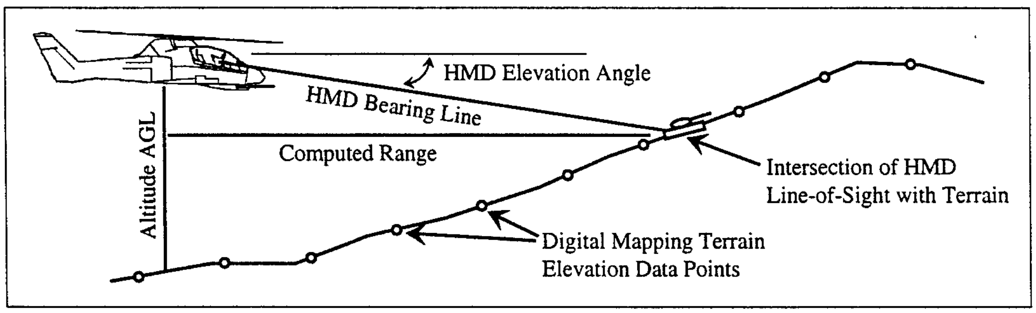


Figure 4-9. The geometry of passive ranging with the HMD.

A passive ranging capability with a cued LOS symbol would eliminate the possibility of detection of laser energy by the enemy, reduce the risk of detecting voice traffic, and speed the target hand-off process significantly. In addition, it would prevent the inadvertent lasing of friendly troops.

Thus, for attack missions, the attack team leader could provide fire directions by turning his head to direct a head-referenced HMD cursor to a target then, by manual or voice control, transmit the target to a team member. The recipient's system would instantly perform the geometric computations to position an earth-referenced HMD cursor on the same target. Not only would such a capability be immensely superior to current voice fire control procedures, it is even more rapid and accurate than the commander leaning over the pilot's shoulder to point out a position in the terrain (assuming this were possible).

Although target hand-off functions are the most obvious application of the real-world pointing capability, any communications that are used to indicate locations of tactical positions, terrain features, or other geographic data can be greatly aided by this HMD display technique.

Communication with the TOC. The same kind of technique is also valuable for transmitting report information to the TOC or ground unit commander. Currently, if a pilot sees a potential target in the real world and wants to determine the precise location of the target site without risking exposure by lasing, he must determine his present location from the navigation computer, estimate range and bearing to the target from his own position, and attempt to determine the UTM coordinates on a paper map. These 6- or eight-digit grid coordinates are then transmitted to the recipient for plotting on another map.

With the HMD (and a digital terrain database), the pilot would simply look at the target, bringing a location-marking cursor over the target position. The computer system would then calculate the HMD line-of-sight and terrain grid coordinates. Such a system could be used to instantly place a symbol on a digital map display corresponding to the computed target location, and at the pilot's command, to transmit this position to the TOC. The TOC could, in return, data-link important position, line, or area data to the unit commander for optional display via the commander's HMD, overlaid on the terrain. Importantly, problems of mistaken landforms or geographic coordinate identification errors are not introduced in either process.

Masking and Intervisibility Issues. The HMD can present specific line-of-sight, cover, and concealment information in the views and formats most compatible with the pilot's requirements when evaluating masking, fields of fire, backdrop, and related questions.

An HMD application in this area is the enhancement of various line-of-sight computations by presenting the three-dimensional forms that are not readily presentable with a top-down view. For example, a difficulty with depicting threat weapon effectiveness envelope on the digital map alone is that the top-view cannot show the potential changes in the envelope, based upon differences in altitude above the ground. With the head-up view offered by the HMD, the vertical profile of the threat weapon envelopes could be depicted by such symbology, as shown in Figure 4-10.

In addition, the HMD could use symbols to show the pilot the location of any given point (such as a waypoint or an enemy weapon) and use some visual code to indicate whether the position is actually visible from the current location, or is positioned behind the currently visible terrain. Such a capability will be described in more detail in Section 6 of this report.

Furthermore, as new enemy situation information is transmitted to the aircraft, the HMD can also be employed to warn the pilot of his potential visibility to enemy weapons, and suggest routes to the closest cover and concealment.

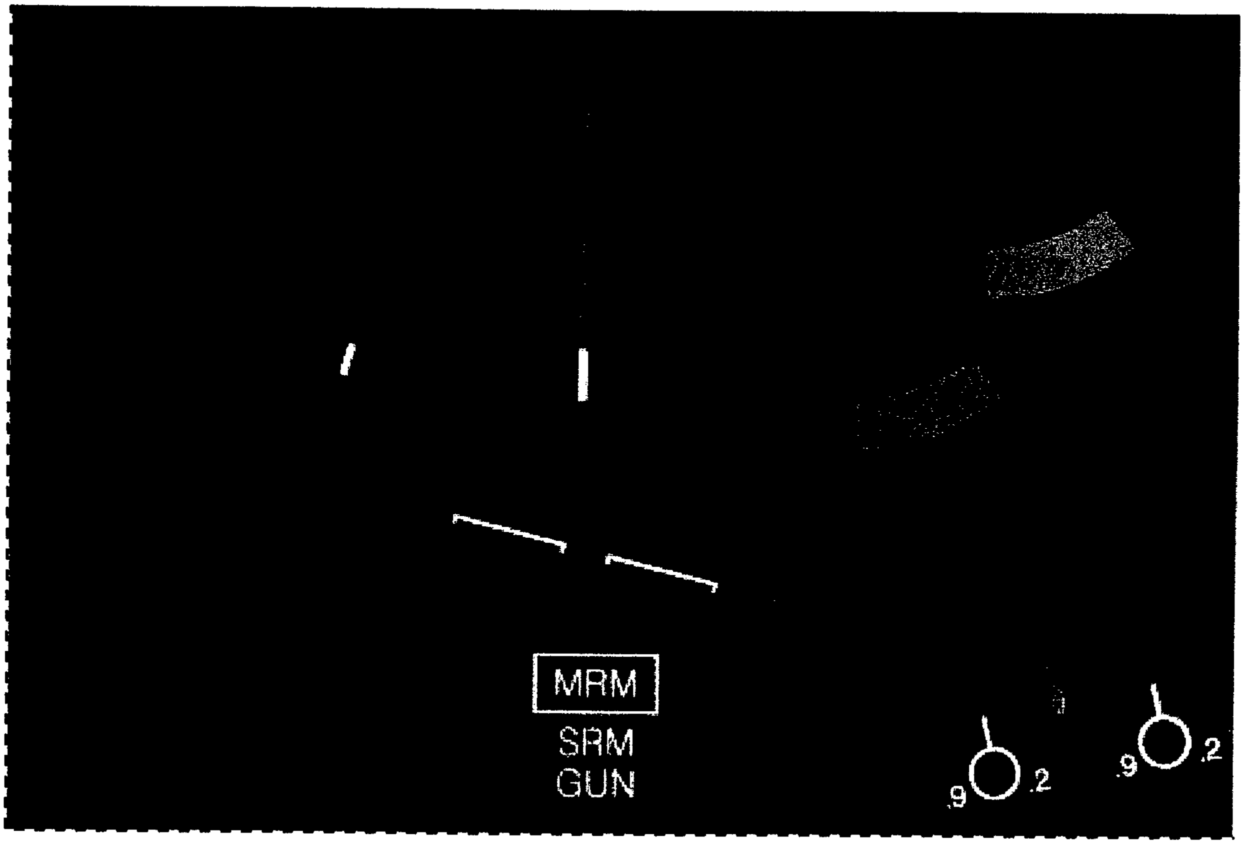


Figure 4-10. A fanciful example of an HMD 3-D threat representation suggested for the Advanced Tactical Fighter (Northrop/McDonnell Douglas, 1988).

Mission Information Requirements Analysis and HMD Symbology

In order to examine the variety of new HMD symbols potentially valuable to the pilot, it is first necessary to analyze the required information content of the symbols. The most effective way to proceed is to extend the traditional task analysis to create a cognitive task analysis approach. To extend the list of candidate symbols, intensive interviews with expert pilots and surveys of symbol importance must also be conducted. In addition, in order to accommodate future information requirements, careful examination of MEP additions must be undertaken for each new project.

Identify Emerging HMD Mission Information Presentation Opportunities

During the Phase I effort, we had selected a set of in-flight activities to create a representative range of information elements and pilot information processing functions. The activities were specifically selected to include events associated with changing symbology needs. In order to ensure that supporting SMEs would be available, current AH-64 tasks served as the pool from which the to-be-analyzed activities were drawn. For the Phase II effort, we put additional emphasis on the types of mission functions that will be representative of those to be conducted by aviators in the foreseeable future, in more advanced aircraft and using more powerful avionics capabilities, so that our findings would be applicable over the long-term.

In particular, we believe that HMD systems hold promise for solving problems in the areas of tactical communications, terrain interpretation, masking and intervisibility determination, geographic orientation, and situation awareness. We attempted to identify the additional pilot tasks and related information elements, and specify ways that the required HMD capabilities would change as a result of these improvements. Some examples of these changing tasks and technologies are described in this section.

Historically, most task analyses have been based largely on the control inputs and display outputs of selected MEP components. In failing to examine the specific applications of these components, the simultaneous task requirements of combat and the resulting workload thrust upon the pilot, such analyses do not always reveal the information elements that most directly support the pilot in meeting special operational problems.

To have an in-depth understanding of the current problems in acquiring, interpreting, and using battlefield data in the cockpit, it is critical to determine the impact of the information requirements within the context of mission management functions, examine the current sources of the necessary information and, by inference, the deficiencies experienced in an on-board setting. Based on such analyses, and upon extensive interviews with SMEs from operational units, it is possible to identify the salient information problems posed by current systems and suggest feasible contributions to be made by improved HMD systems.

Source of the Task Analysis and Workload Information

For many years Anacapa Sciences has performed task analysis and workload studies for the Army, employing teams of psychologists and helicopter pilots to capture analytic data useful in designing and evaluating new aircraft and avionics concepts. Several years ago (Hamilton, Bierbaum, & Rogers, 1992) we began a series of analyses to extend the existing data to address HMD issues. The existing databases identifying AH-64 Apache mission phases, segments, functions, and tasks were further decomposed into lists of individual information elements required to perform the tasks in a scout-attack mission, and the specific attributes of each information element were categorized.

The analyses were iteratively reviewed by Army pilots and psychologists and organized into a relational database called the Task Analysis and Work Load Operator Relational Database for Information Requirements, or TAWL ORDIR. By the conclusion of the effort (Hamilton, Rogers, & Spiker, 1995), some 9 phases, 86 segments, 234 functions, 554 tasks, 567 requirements, and 667 information elements had been identified for the conduct of attack and reconnaissance missions. The mission analysis document uses a hierarchical, semi-chronological approach to putting the information elements in a meaningful context and is presented in a two-volume, 1200-page report.

TAWL ORDIR System Design and Organization

TAWL ORDIR was developed by Anacapa Sciences to perform human factors analyses of complex system requirements (Hamilton, Rogers, & Coker, 1994). This

relational database was designed to dynamically store, organize, and display the enormous amount of information that is inventoried during analyses of complex systems, increasing analyst productivity and enhancing the utility of the resulting analytical research data. The software stores the data in a manner that facilitates the development, maintenance, and documentation of the analysis using a graphical user interface and a series of on-line and printed reports.

The basic structure of TAWL ORDIR databases, shown in Figure 4-11, supports the conduct of top-down mission and information analyses. Mission analysis components are identified at the six levels presented in the boxes on the left of the figure: segments, functions, tasks, requirements, elements, and sources. Each of the components identified during the mission analysis is stored in the system as a simple list or "flat file." The items in each of the lists are then related to items in the level of analysis just above and below them. Thus, to define the tasks in a function, data are stored that relate that function to its constituent tasks. Similarly, functions are related to the segments in which they occur. These relations are represented in the figure using arrows to link the levels of the mission analysis.

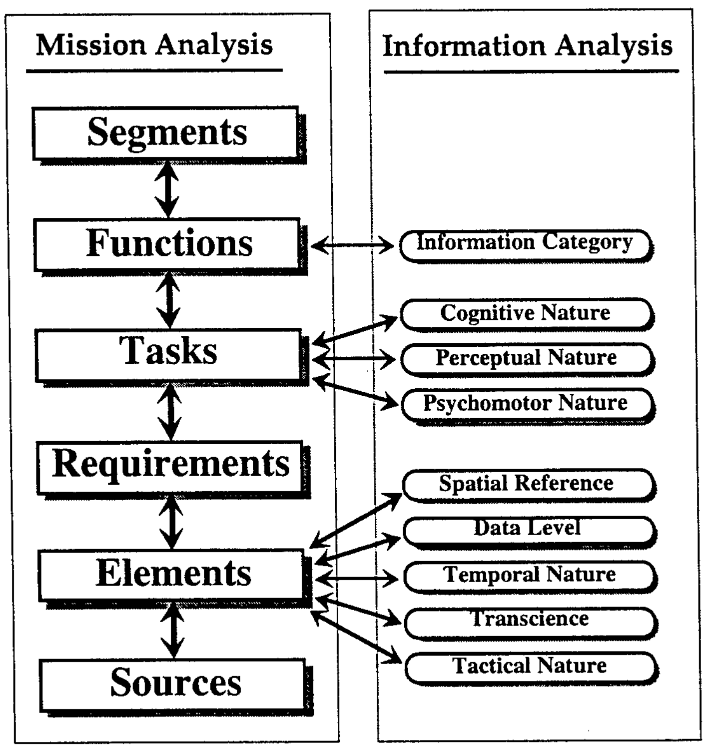


Figure 4-11. The organization of TAWL ORDIR databases.

The information analyses include information attribute ratings for the nine information attributes presented in boxes on the right-hand portion of the figure. Attribute ratings are made at different levels of the mission analysis. As can be seen from the figure, one attribute is rated at the function level (Information Category); three attributes are rated at the task level (Cognitive, Perceptual, and Psychomotor Nature), and five attributes are rated at the element level (Spatial Reference, Data Level, Temporal

Nature, Transience, and Tactical Nature). Attribute ratings are defined in the database by storing data that relate the mission components to their constituent information attribute ratings. These relations are represented in the figure using arrows to link the information attributes with the components of the mission analysis.

For HMD symbology designers, the most important level of analysis is that of identifying the information elements that are needed to meet the pilot's information requirements. Information elements are the units that must be monitored, interpreted, transformed, and integrated by the pilot to view the desired and actual state of the system and to answer the questions posed by the information requirements. For example, the answer to the question "Is stable flight being maintained?" is provided by the information elements "Vertical clearance of obstacles," "Horizontal clearance of obstacles," "Altitude above ground level," "Airspeed," "Ground speed," "Pitch," "Roll," "Drift direction," and "Heading to feature."

This portion of the analysis was especially important because the information elements identified during this process define what must be available to the pilot, either from the mission equipment and aircraft displays or from the pilot's perceptual analysis of the available sensor images or out-the-window views. Importantly, the resulting list of information elements forms the baseline for evaluating a display system and helps to identify deficiencies, duplications, conflicts, or other shortcomings in the content of the information presented, as well as provide clues to the development of new and superior display systems.

We have found TAWL ORDIR to be particularly useful in considering intelligent symbology management because of its ability to immediately determine and display the information elements used in any segment, function, or task, or the specific segments, functions, and tasks that require a given information element. In addition to aiding in these analyses, TAWL ORDIR could also be used for rapid retrieval of information elements for discussion during the SME interviews.

For example, as shown in Figure 4-12, TAWL ORDIR allows the investigator to select one or more information elements from the list of elements and to request lists of the mission components (such as segments, functions, and tasks) in which those elements are required. Alternatively, the investigator can display the mission components in which those elements are not required. This type of procedure is useful for determining the relative frequency of use and the criticality of selected information elements.

In addition, we used these procedures to select one or more functions from the list, and then generate a list of the information elements required to perform the selected functions, as shown in Figure 4-13. Applying this approach, we could instantly define the apparent set of information requirements for display modes tailored to support a particular set of mission functions. Carrying the database on a laptop computer, we were able to review those information elements with SMEs at both Fort Rucker and West Jordan by constructing, "on-the-fly," sets of necessary elements to serve in various tasks or functions.

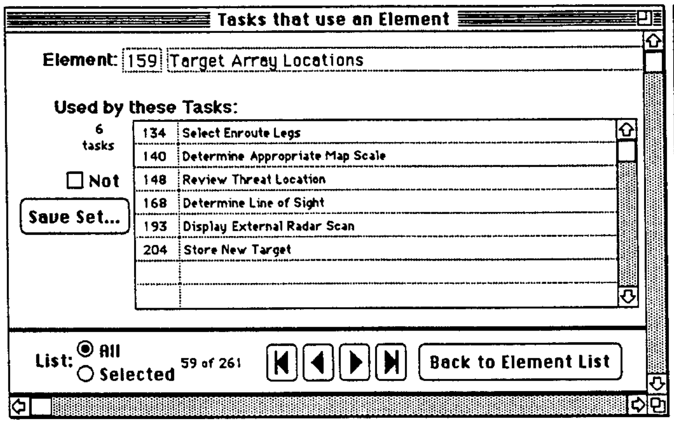


Figure 4-12. The information element view in TAWL ORDIR.

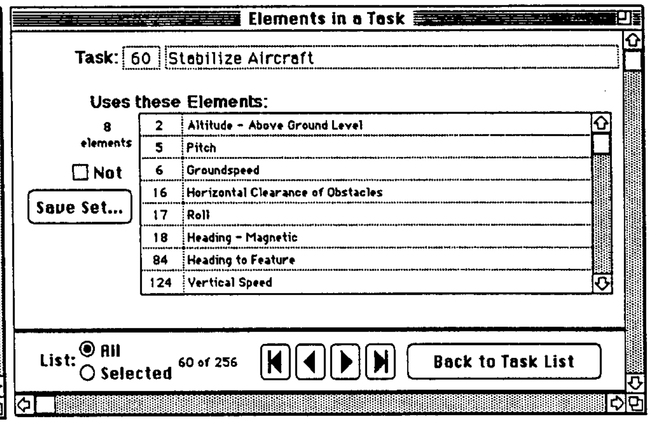


Figure 4-13. The mission components view in TAWL ORDIR.

The TAWL ORDIR Mission Analysis Report

TAWL ORDIR was designed to be flexible both in the structure of the information stored in its databases and in its functional capabilities. The design specifications have emphasized the storage, display, and documentation of the information gathered during task and information analyses. Several types of TAWL ORDIR on-line and printed reports have been developed. The easiest to understand, however, is the Mission Analysis Report because of its hierarchical organization. It is similar to traditional task-analytic techniques in its presentation of mission analysis data in a semi-chronological fashion.

For example, each line on the screen shown in Figure 4-14 presents one labeled component of the mission analysis. The first line of the report, labeled "segment," gives the segment name (NOE Flight) and shows the segment identifier in parentheses (1). The second line introduces the first function, gives its name (Retrieve Saved Message), and shows the function identifier (105). The third line introduces the first task, gives the task name, and shows the task identifier. Similarly, one requirement with two information elements and their associated sources are given to complete the description for the first task in the function. The other tasks in the function are then described in sequence. The order of the tasks in the functions is consistent with the order in which they are expected to be performed during the mission. Functions are repeated under each segment in which they occur.

Segment → **NOE Flight (1)**
  Function → Retrieve Saved Message (105)
    Task → **Enable/Disable Message Retrieval (250)**
      Requirement → Has the message been retrieved? (228)
        Element → **Time of Arrival (93)**
          Source → Digital Message Content (28)
        Element → **Time of Activity (95)**
          Source → Digital Message Content (28)

Figure 4-14. A portion of the Mission Analysis Report for one segment of the mission.

The completed mission analysis document offered a hierarchical, semi-chronological approach to putting the information elements in a meaningful context and, when printed out, resulted in a two-volume, 1200-page report.

Identifying Potential HMD Applications

To identify the individual information elements that could beneficially be presented on the HMD, we employed the TAWL ORDIR information requirements data as presented in the 1200-page Mission Analysis Report. The objective was to pass the information requirements data through a series of logical "filters" to identify tasks for which the information elements might best be presented on the HMD. A psychologist and an Apache subject matter expert painstakingly combed through the report in attempting to systematically reduce the list of elements to only those that might be found on a future HMD system with intelligent moding.

The first filter was the selection of mission segments and tasks that clearly involve the use of the HMD, including all flight and tactical engagement components. TAWL ORDIR sorts were performed to identify all elements required to perform every applicable mission segment and function.

For example, a sort of "Segment 14, Landing," results in a list of information elements such as "Altitude AGL," "Pitch," "Roll," "Torque," and some less expected elements such as "Status-tailwheel" and "Looming objects." To further explore the nature of these elements, TAWL ORDIR was used to observe them in the context of a Mission Analysis print-out, showing the hierarchical relations of mission segments, functions, tasks, and elements. Figure 4-15 shows a portion of the landing sequence from a TAWL ORDIR Mission Analysis printout. The analysis shows tasks, information requirements, information elements, and information sources in context.

Additional information analysis options from TAWL ORDIR include Mission Timeline Reports, which orders the pilot's functions by when they are performed in time, as well as the predicted workload in cognitive, visual, auditory, and psychomotor categories as they are associated with the moment-to-moment pilot activities. High workload prediction ratings are particularly useful in identifying opportunities for automatic intelligent symbology management of individual information elements.

The selection of the subsequent series of filters was based on the established benefits of HMD systems. First, a primary advantage of the HMD is simply that it minimizes head-down time, a particularly valuable asset for terrain flight in military helicopters. Thus, tasks most requiring that the pilot scan the surrounding terrain and airspace were closely inspected for opportunities to intelligently present required information elements.

Another filter addressed the ability of the HMD to present conformal symbology in which the symbol element that represents a real-world feature actually marks the feature's location in the pilot's field of view, staying on that marked position even as the pilot moves his head. As Weintraub (1994) has noted, "Conformality is a critical advantage that cannot be duplicated head down if the eye must also gather information

→ **Transit to Forward Rendezvous (4)**

- *Function* → Land Aircraft (26)
  - *Task* → **Control Attitude (4)**
    - *Requirement* → Is the aircraft nose too high? (4)
      - *Element* → **Pitch (5)**
        - *Source* → Heading and Attitude Reference System (9)
        - *Source* → Visual Scene (sensor) (28)
    - *Requirement* → Is the aircraft nose too low? (5)
      - *Element* → **Pitch (5)**
        - *Source* → Heading and Attitude Reference System (9)
        - *Source* → Visual Scene (sensor) (28)
    - *Requirement* → Is a wing too low? (6)
      - *Element* → **Roll (17)**
        - *Source* → Heading and Attitude Reference System (9)
        - *Source* → Visual Scene (sensor) (28)
    - *Requirement* → What is the flight director's pitch command? (532)
      - *Element* → **Pitch Command - Flight Director (529)**
        - *Source* → Automatic Flight Control System (22)
    - *Requirement* → What is the flight director's roll command? (533)
      - *Element* → **Roll Command - Flight Director (528)**
        - *Source* → Automatic Flight Control System (22)
  - *Task* → **Maintain Obstacle Clearance (32)**
    - *Requirement* → Is the aircraft high enough to clear obstacles? (2)
      - *Element* → **Distance Vertical from Obstacles (454)**
        - *Source* → Visual Scene (sensor) (28)
    - *Requirement* → Turn / move to avoid obstacles? (7)
      - *Element* → **Distance Horizontal from Obstacles (16)**
        - *Source* → Visual Scene (sensor) (28)
  - *Task* → **Control Drift (36)**
    - *Requirement* → What is the magnitude and direction of aircraft movement? (41)
      - *Element* → **Speed Ground (6)**
        - *Source* → Navigation System (15)
        - *Source* → Visual Scene (sensor) (28)
      - *Element* → **Drift Direction (83)**
        - *Source* → Navigation System (15)
        - *Source* → Visual Scene (sensor) (28)
  - *Task* → **Control Heading for Stable Flight (50)**
    - *Requirement* → Is the aircraft heading steady or changing at a steady rate? (52)
      - *Element* → **Magnetic Heading - Ownship (18)**
        - *Source* → Heading and Attitude Reference System (9)
      - *Element* → **Heading to Feature (84)**

Figure 4-15. Example from TAWL ORDIR Mission Analysis printout.

directly from the visual environment." Thus, we studied the task-analytic data to identify the pilot functions involving specific cartographic or terrain positions that could be intelligently presented by "augmenting" reality (i.e., superimposing symbology on real-world locations as viewed through the HMD).

Yet another filter was related to the HMD's very direct method of "pointing" at features in the environment and cueing the CPG, or other HMD-equipped aviators in other friendly aircraft, to look at the position pointed out. Tasks involving these types of elements were scrutinized for intelligent display opportunities.

In short, the objective was to search the mission data, item-by-item, for cases in which the established criteria for HMD use were applied to the functions, tasks, and information requirements described in the task analysis data. These cases were recorded for use during the subsequent SME interviews and survey so that the apparent "hits" could be confirmed.

To maintain their focus on the objective of the analysis and its logical filters, the review team members were guided by eleven ground rules for including elements or excluding elements, as described below.

First, it would almost always be important to include elements that are:

1. Required for tasks that clearly involve HMD use, such as gun aiming.
2. Used during tasks that demand head-up viewing, such as flight control
3. Potentially located by HMD pointing and cueing symbols (e.g. wires)
4. Refer to spatial positions, lines, or areas on or above the earth.

Second, it would almost always be important to exclude elements that are:

1. Used only in the Mission Preparation phase, before the HMD is donned.
2. Part of the real-world scene, such as trees or rivers (direct view or sensor)
3. Necessarily in the form of extensive text like checklists and orders.
4. System status information such as intercom mode, or chaff dispenser mode
5. Current system configuration such as exterior lighting and de-icing
6. Specific system advisories (beyond a master warning or caution indicator)
7. Voice communications (unless the data might better be presented on the HMD.

Although tedious, it was more useful to go through the 1200 pages of mission analyses than to simply examine a list of the 667 information elements because the mission analysis report presented the information elements in the context of mission functions and tasks. Simply examining a list of the 667 information elements would not always have made evident the value of an HMD symbol. Furthermore, when examined in context, the same element might be included or excluded, depending upon the differing nature of the mission tasks.

Results of the Review

The results of the review were that 124 information elements were identified as potentially useful on an HMD display. The elements are listed below, along with their identifier numbers in the TAWL ORDIR data base. The information elements have been

grouped into five categories: aviation & navigation, threat & weapons management, zones and positions on earth, positions in image, zones and positions in space.

Aviation & Navigation

2. Altitude - above ground level
3. Speed air
4. Yaw
5. Pitch
6. Speed ground
16. Distance horizontal from obstacles
17. Roll
20. Altitude - relative to surrounding terrain
43. Torque - total
79. Wires
81. Towers
83. Drift direction
84. Heading to feature
88. Target bearing
106. Torque - engine #1
107. Torque - engine #2
116. Altitude - mean sea level
117. MSL altitude - planned
124. Speed vertical
125. Local terrain topology
238. Speed ground - planned
305. Speed air - minimum single engine
375. Time before damage by high torque condition
483. Distance - object of interest
454. Distance vertical from obstacles
501. Altitudes - minimum obstruction clearance
502. Altitudes - minimum enroute
527. AGL altitude - planned
528. Roll command - flight director
529. Pitch command - flight director
665. Looming objects
666. Objects of interest

Threat & Weapons Management

7. Distance to most dangerous threat
8. Bearing to most dangerous threat
9. Threat searching
10. Threat lock-on
11. Missile launch - threat
13. Missile constraints
14. Status - weapon launch
15. Missile separation
18. Magnetic heading - ownship
19. Magnetic heading - planned
21. Threat intervisibility
23. Selected weapon
26. Rate - gun fire
36. Enemy fire
60. Time of guided missile flight
173. Altitude - target array
177. Guided missile launch - ownship
348. Code - range finder
396. Status - fire and forget missile tracker
402. Time to designate
443. Status - air to air missile tracker

Zones and Positions on Earth

25. Position on earth - marked
70. Positions on earth - intersections
137. Positions on earth - ground targets
144. Positions on earth - friendly artillery
145. Positions on earth - active artillery
148. Zone on earth - assigned attack
150. Zones on earth - friendly locations
159. Zones on earth - enemy locations
161. Zone on earth - fire
163. Zones on earth - no fire
165. Positions on earth - threat locations
174. Remote location's view of battlefield
175. Remote location's cover
176. Remote location's concealment
179. Positions on earth - ground targets detected by radar
154. Position on earth - checkpoints
262. Zone on earth - kill
394. Overlay - air strike missions
397. Overlay - flight hazards
412. Positions on earth - selected ground targets
437. Zone on earth - target area
485. Position on earth - selected air strike mission target
486. Position on earth - selected artillery mission target
506. Zone on earth - weapon impact area
538. Positions on earth - ownship's projection
544. Positions on earth - navaids
545. Positions on earth - airports
600. Positions on earth - force boundaries
609. Zones on earth - engagement areas
620. Positions on earth - holding areas
621. Positions on earth - phase lines
636. Positions on earth - FARP locations
641. Positions on earth - downed aviator pickup points
652. Positions on earth - assembly areas

Positions in Image

29. Position in image - helmet pointer
35. Position in image - ownship location on map
37. Positions in image - targets detected unaided
61. Positions in image - targets detected sensor
390. Position in image - air to air missile tracker
391. Position in image - fire and forget missile tracker
508. Position in image - object of interest

Zones and Positions in Space

32. Zones in space - threat lethality
41. Positions in space - actual flight route
89. Position in space - next to shoot target
100. Position in space - refueling tanker
147. Positions in space - flight team members
152. Position in space - selected waypoint
153. Positions in space - selected flight route
156. Positions in space - active flight route
157. Positions in space - waypoints
160. Zones in space - restricted areas
162. Position in space - active waypoint
172. Position in space - rendezvous aircraft
392. Position in space - home waypoint
482. Position in space - helmet boresight
530. Positions in space - air targets
531. Positions in space - air targets detected by radar
536. Position in space - refuel location
537. Position in space - ownship present position
552. Positions in space - initial approach fixes
554. Positions in space - step down fixes
561. Positions in space - instrument approach
562. Positions in space - missed approach
567. Position in space - final approach fix
568. Position in space - missed approach point
569. Positions in space - approach holding patterns
617. Zones in space - air routes and corridors
618. Positions in space - air control points
619. Positions in space - rally points
622. Positions in space - battle positions
651. Zones in space - NBC contamination

Mission Equipment Package Implications for HMD Symbology

The preceding pages have described the operational requirements "pull" on HMD symbology design through consideration of the mission task information that must be processed by pilots of scout-attack rotorcraft. It is important to remember, however, that there are HMD symbology design issues stemming from the technology "push" of ever-increasing avionics capabilities. The particular mission equipment package (MEP) installed in the aircraft serves to constrain and shape the type, amount, and flow of information to the pilot. Advanced avionics technologies will greatly change the information available to the pilot in the near term. For example, the Rotorcraft Pilot's Associate (RPA) may provide "cognitive decisions aids" that recommend specific pilot actions; the Obstacle Avoidance System (OASYS) or the Terrain and Obstacle Detection Sensor (TODS) may provide advance warning of wires and towers in the flight path; the Integrated Air-to-Air Weapon (INTAAW) may improve the short-range effectiveness of an automatic cannon; Tactics Planning Expert Functions may generate flight routes based on the threat situation; advanced Data Transfer Systems may permit storage and transmission of massive amounts of mission planning data; and advanced ASE may present integrated lethality data.

Traditional information requirements, such as "where is the enemy?" have not changed over the years. However, as the above sample of new technologies shows, emerging systems will address these traditional requirements in dramatically different ways. Less obvious are the impacts these technologies will have on HMD symbology. The particular mission equipment package (MEP) installed in the aircraft serves to

constrain and shape the type, amount, and flow of information to the pilot. Since the HMD is the pilot's window not only to his flight and tactical environment, but also to the new information available from the MEP operational and technical capabilities, effectively presenting the new symbology without cluttering the field of view is critical, and success will almost certainly be dependent upon developing an intelligent symbology management system.

Avionics Context of the HMD

Needless to say, effective HMD symbology design cannot proceed without considering the avionics context in which the HMD itself will operate. That the aircraft will have an HMD implies that some decisions about its associated MEP configuration (e.g., using an HMD in lieu of a HUD, making extensive use of advanced night sensors) will likely have been made. But once the HMD has been included in the MEP, more fine-grained decisions concerning the selection and design of its symbology must inevitably depend on the specific avionics systems that will serve as the source for the various to-be-displayed information elements.

As the name suggests, an MEP is configured to accomplish the specific missions assigned a given aircraft. Our focus has been on scout-attack weapon systems, which in comparison to their fixed wing counterparts, are highly weight-constrained. As such, many avionics, while technologically quite feasible, simply cannot be put into the cockpit. Even compared to heavier utility and lift helicopters, scout-attack avionics are quite limited. A case in point is the Air Force's Special Operations Forces (SOF) MH-53J Pave Low III heavy lift helicopter. The Pave Low contains a number of advanced (but heavy) technologies not found in Army scout-attack helicopters. These include terrain following/terrain avoidance radar, advanced electronic countermeasures (ECM) and jamming, hover coupler control, and integrated defense avionics (Spiker, 1995).

The impact of size and weight constraints on scout-attack avionics selection is an important consideration, as it determines the technology "filter" through which the symbology must pass. In this regard, refueling tactical aircraft during a mission is especially risky, whether from the air or the ground. Air-to-air refueling requires that aircraft ascend to higher tanker altitudes, exposing all to enemy groundfire. Landing at a ground-positioned FARP is equally dangerous, as complex logistics are required to ensure safe ingress and egress. Consequently, there is a tactical requirement to save as much weight as possible for fuel, in order to increase the aircraft's operational range.

During Desert Storm, for example, both two battalions of AH-64As deployed in Iraq were outfitted with the extended range fuel system (ERFS). The ERFS contains auxiliary fuel tanks that permit the heavy Apaches to fly 700nm without refueling. On the first night of the war, the Apaches that destroyed the Iraqi air defense sites were equipped with the ERFS so that the FARP could be located as far from the FLOT as possible.

As another example, recent specifications for the US Army's next-generation scout reconnaissance aircraft, the RAH-66 Comanche, imposed a stringent weight limit of 7500 pounds. This would let the Comanche increase its self-deployment range from

800nm, the present maximum for scout-attack aircraft, to 1260nm. To achieve this goal, however, many desirable information-bearing avionics had to be classified as "nice to have," but not as essential as additional fuel. Some years ago, such niceties included HUDs, ground mapping radar, and digital maps. Now, they include wide screen head down displays, more capable mission computers, and integrated FLIR/radar sensors. While such capabilities are routinely found on fixed-wing tactical aircraft (e.g., F-15E, F-16C/D), they are often merely overly heavy, nice-to-have MEPs for helicopters.

However, despite the chronic need to minimize rotorcraft weight, the rapid pace of modularizing and miniaturizing avionics has produced an explosion of information in even the most constrained cockpits. Indeed, such trends as line replaceable units (LRUs), line replaceable modules (LRMs), digital data buses, and secure communications have dramatically increased information throughput to the pilot. This, in turn, has placed more demands on HMD symbology design, to ensure that the burgeoning information is presented and managed in ways that do not overwhelm the pilot's limited perceptual, cognitive, and psychomotor capacities. In particular, the avionics-induced shift toward decreasing the pilot's psychomotor workload while simultaneously increasing the demands on his cognitive resources has important implications for one's strategy toward HMD symbology development.

To clarify the nature of the symbology issues, it is useful to subdivide the avionics capabilities into nine functional classes of MEPs. These are shown in Table 4.1. This classification is not intended to represent the physical form of the avionics in the cockpit, as some MEPs in a given class may reside in physically disparate locations (e.g., the different navigation subsystems). Rather, the intent is to organize the description of MEP capabilities along *functional* lines in order to support systematic analyses of MEP information requirements.

It will be important for symbology designers to structure a general-use procedure for analyzing MEP information requirements and assessing their impact on HMD symbology design. Unlike the task analysis approach, MEP analysis is not a formal methodology, nor does it have a rich empirical database on which to draw. Instead, the design team must go through a series of steps—some analytic, some conceptual—to determine the information that is available from the avionics. Once the available information has been identified, the team must then use their knowledge of how the avionics systems function to determine which MEP component (e.g., navigation system, ASE, etc.) will serve as the source for each required information element.

As with other aspects of HMD symbology development, the key is to characterize avionics functioning at the *information requirement and information element* levels so that the optimum content, location, format, referencing, and behaviors for HMD symbols may be determined. In this analysis, the design team must resist the temptation to make engineering-only assessments which stress electronics and "black boxes" to the exclusion of display information that must be perceived, processed, and acted upon by the pilot.

Ideally, the MEP avionics support the pilot's information requirements as defined during task analyses. As the MEP for a given aircraft becomes more defined, the design

team can begin to consider how well the chosen avionics satisfy the aviator's information needs. An MEP analysis should use the results from the information requirements analysis to determine the avionics that can serve as the source for each information element. The primary purpose is to identify those required information elements for which the proposed MEP configuration do not provide a suitable avionics source.

Table 4.1.
Classification of MEP Functions for US Army SCAT Rotorcraft

MEP Functional Class	Classification Rule
1. Flight Control	Processing of flight control data (e.g., altitude, velocity) for other uses (e.g., automated hover hold)
2. Sensors	Electronic and display augmentation of pilot vision (e.g., Laser Range Finder, FLIR, terrain following radar)
3. Weapons Management	Recording and display of planning-related weapons data (e.g., range, number, trajectory)
4. Target Acquisition	Equipment and display aids to detect, acquire, and engage targets (e.g., laser spot tracker, automatic target recognizer)
5. Navigation	Position-location, position-updating, and route selection equipment (e.g., Doppler radar, map, INS. GPS)
6. Aircraft Survivability Equipment (ASE)	Threat detectors (e.g., RWR), threat identifiers, missile jammers or evaders
7. Voice Communication	Radio transmission and reception of airborne or ground-based voice messages (e.g., UHF, VHF, HF radios)
8. Data Link	Reception, storage, and transmission of airborne or ground-based digital data (e.g., ATHS)
9. Battlefield Awareness	External systems to provide battlefield information (e.g., Joint tactical information distribution system [JTIDS], EPLRS) on a real- or near real-time basis

Analytic Approach to MEP Evaluation

The design team can use several different analytic methods to link the avionics sources to required information elements. One way is to employ a spreadsheet approach like that depicted in Table 4.2. For this example, we have taken selected required information elements from the TAWL ORDIR analysis performed by Anacapa Sciences (Hamilton, Bierbaum, & Rogers, 1994). In particular, the left column of Table 4.2 displays seven of the required information elements from the Select Ambush Position function of the Target Acquisition mission segment. The two right-most columns indicate the task and information requirement associated with each element.

For this analysis, Columns 2-4 are of greatest concern. Column 2 lists the generic source for the information based on the TAWL ORDIR analysis. As the MEP becomes more defined, the design team will replace the generic source with a more specific avionics source in Column 3. As can be seen, specific sources are identified for the first

four elements in the table. Thus, the availability of an electronic aeronautical chart, FLIR, GPS, and the mission computer will serve as sources for the kill zone, aircraft altitude, terrain topology, and current line of sight (LOS) with the target area.

Table 4.2.
Identifying Specific MEP Sources for Required Information Elements

Information Element	Generic Source	Specific Source	If N/A	Task	Requirement
Zone on Earth - Kill	Map	Annotated aeronautic chart		Identify Kill Zone	Where is the kill zone located?
Altitude - Relative to surrounding terrain	Nav System & Visual Scene Sensor	GPS and FLIR		Determine line of sight	Is there inter-visibility with target area?
Local terrain topology	Map and Visual Scene Sensor	Aeronautic chart and FLIR		Determine line of sight	Is there inter-visibility with target area?
Positions on Earth - Ground Targets	Mission Computer	MC operating on prestored coordinates		Determine line of sight	Is there inter-visibility with target area?
Altitude - Target Array	Map	N/A	Aero chart lacks DTED to determine LOS between A/C alt. and tgt MSL	Determine line of sight	Is there inter-visibility with target area?
Remote Location's Cover	Map	N/A	Aero chart lacks crown cover computations to determine pos. that optimizes cover for a given A/C AGL- tgt MSL combination	Identify cover and concealed position	Which position has best cover & concealment?
Remote Location's Concealment	Map	N/A	Aero chart lacks DTED and vegetation computations to determine pos. that optimizes concealment for a given A/C AGL - tgt MSL combination	Identify cover and concealed position	Which position has best cover & concealment?

On the other hand, the bottom three information elements do not have specific avionics sources for optimizing LOS, cover, and concealment. In this case, we have assumed that while the avionics suite provides a two-dimensional aeronautical chart, it does not have a three-dimensional digital map with associated DTED and DTED-based computations. For these elements, a not available (N/A) indication is placed in Column 3. In Column 4, we provide descriptive information that the design team would use to summarize the reasons why information is not available and what would be required to

obtain it. These descriptions can be collected over the entire array of information elements and MEP possibilities, and applied to subsequent steps of the analysis.

While the systematic application of an analytic approach such as that that described here is typically unusual, the practice of comparing the MEP contributions with the pilot's information requirements is crucial to both head-down and head-up HMD symbology definition. The number of unmet information requirements must be minimized and the impact of new information elements and symbols imposed by more powerful avionics systems must be identified as early as possible.

Conclusions

For the purposes of this project, we have not attempted to identify and list a series of new symbols based upon some predicted MEP for a future helicopter. Instead, knowing that we cannot foresee all of the important variables, we have chosen to closely examine what we believe to be a collection of new symbols that are broadly representative of classes of new symbology types expected to emerge in the near future. Furthermore, we have attempted to develop a flight simulator expressly designed for the evaluation of anticipated as well as unforeseen symbology types. The following section of the report describes the development of this simulator.

Section 5: PRISMS Design and Development

Introduction

The Need for a Simulator

At the close of the Phase I effort, the combined results of the information requirements analyses, the simulator flights, and the SME interviews had led us to conclude that there were a great many ways that intelligent symbology management might be incorporated to aid pilots in performing flight and mission tasks. The mission information analyses of Phase II greatly strengthened this conclusion. Furthermore, we recognized that the "innovative intelligent symbology management system" should be a system that would be applicable beyond any one specific aircraft. Thus, although we had chosen to focus on the characteristics of the AH-64A aircraft because of the availability of SMEs, the products of the research needed to be extendible beyond the AH-64 and its specific equipment.

It became evident that the extended applicability of our products should take two different forms: first, a broad relevance of research results to similar situations on different aircraft and second, a continuing value of the research methodology itself in identifying opportunities for intelligent symbology management. We have identified well over one hundred information elements that might be displayed as new symbols on the HMD to the benefit of the pilot. Each of these would require additional research in defining the specific information content, format, behavior, and intelligent moding. Only a small fraction of the required research could be addressed within the scope of this contract.

In accordance with these beliefs, the thrust of our Phase II project was not only aimed at providing some important new HMD symbols and sets of rules for their presentation or decluttering, but also at providing a sophisticated simulator system and a reliable operational methodology for the continued use of the rulebase in discovering and implementing intelligent symbology management opportunities. This section of the report further describes the simulator design philosophy and the way in which it grew throughout the project.

STRATA Simulator "Flights"

As described in Section 2, preparation for the conduct of the SME interviews during the Phase I effort included use of the sophisticated STRATA (Simulator Training Research Advanced Testbed for Aviation) simulator operated by the U.S. Army Research Institute Aviation R&D Activity (ARIARDA), at the U.S. Army Aviation Center at Fort Rucker, Alabama. Although it was designed as a reconfigurable research testbed, STRATA also provides all the necessary capabilities for an outstanding AH-64 simulator.

STRATA has a database management workstation, equipped with a special interface for experimenters (or mission planners) to enter new mission data. A simple mission might involve navigation through a series of waypoints. More complex scenarios would include wind, bad weather, target acquisition, and engagement. Because our activities were focused on the IHADSS and PNVS symbology issues, the STRATA capabilities were specifically configured so that the project Principal Investigator could experience the IHADSS display symbology under a variety of realistic visibility conditions, and during a range of flight and mission-oriented tasks.

STRATA, with an expert instructor in the second seat, was remarkably effective in illustrating symbol behavior in the Hover, Bob-up, Transition, and Cruise modes. A series of coached flight maneuvers and activities clarified critical HMD symbology issues, and demonstrated the important interactions of various symbol elements. Although the Principal Investigator had been very familiar with the IHADSS symbology from study of the AH-64 manuals as well as from interviews with AH-64 pilots, the increased cognizance of symbology dynamics, interactions, features and problems after flying the STRATA was little less than startling.

As previously described, during Phase I of the effort, we had developed a laptop simulator designed to mimic the appearance and disappearance of Apache HMD symbol elements based upon rule "firing" so as to demonstrate and test the effects of an intelligent symbology manager with Apache instructor pilots. The system was useful in demonstrating symbol appearance and movement, but could not accurately simulate the dramatic effects of pilot head movement or aircraft attitude and movement over the earth on symbol behavior.

In contrast, the STRATA flights enabled us to observe symbology mode changes during a variety of flight maneuvers while closely observing the behavior of the HMD symbology. We found that it is difficult to appreciate the complex dynamics and interactions of HMD symbols without observing them in action while moving the head to different angles and attitudes. The insights gained from a few hours use of STRATA dramatically demonstrated the ability of a high-end simulator to clarify the symbol dynamics and interactions and their meanings. Furthermore, the results of symbology discussions with pilots were vastly more fruitful given the opportunity for both of the discussants to simultaneously observe and comment upon the symbology set in action.

From the STRATA experience it became evident that the use of a sophisticated simulator would greatly enhance the quality of the studies that we could perform and would aid in: integrating knowledge from the research, engineering, and pilot communities; demonstrating established problems and their candidate solutions; and applying the range of research tools in the most meaningful ways.

The advantages of such powerful simulators, however, are accompanied by well-known disadvantages. In general, they are extremely expensive to construct and maintain, require a team of specialized technical support personnel, are time-consuming to reprogram for new applications, and are certainly not portable to

other locations where expert pilots might be permanently or temporarily located. These simulators are also in great demand for major research projects, such as the LHX studies of past years and the current Air Warrior research efforts. Despite the surge of interest in HMD display systems, it is extremely difficult for most research groups to obtain access to these costly and tightly scheduled simulators.

We believed that the only solution to these problems was in the development of a sophisticated, but relatively low-cost HMD research simulator, taking advantage of the most recent advances in technology. Such as system would be so inexpensive as to cost only 1% of current high-end simulators. It would be easy to reprogram, with a point-and-click graphical user interface. It would require no specialized skills to design and conduct studies in a timely manner. It would be easily transportable for use at field sites. Finally, because of its revolutionary cost-performance ratio, it would provide a much broader segment of the research community with the simulation capabilities necessary for the experimentation so urgently needed for the development of new flight systems.

The following pages provide an overview of the PRISMS design and development process. The specific descriptions of the PRISMS features and interface are provided in the system User's Manual.

PRISMS Design Analyses

Since the beginning of the project, and continuing throughout its course, the Principal Investigator at Anacapa Sciences and the System Developer at ThoughtWave conferred almost daily to plan, define, expand, and refine the PRISMS capabilities. Early on, a preliminary set of PRISMS II design requirements was furnished to ThoughtWave to clearly identify the system goals from the user's perspective. These requirements included the specific required capabilities of PRISMS, procedures and capabilities needed for demonstrations, system preparation requirements for experimental research, means for definition of individual symbols and symbol sets, selection of terrain characteristics, and requirements for point, linear, and area annotations of the digitized terrain elevation data.

ThoughtWave responded with an initial effort to identify the hardware and software components that would deliver a PRISMS of the highest possible quality within time and budget constraints. This objective required iterative trade-off analyses of functional requirements; vendor system capabilities, costs, and potential delivery dates; and all of the issues of component compatibility. In fact, the review and analysis was to continue for months into the project as new products became available and prices for others tumbled.

Over time, and after hours of telephonic and face-to-face meetings, the Principal Investigator learned a great deal about the difficulties of system integration and the unsuspected shortcomings of available hardware and software products. In like manner, the System Developer began to appreciate the unusual design requirements of an experimental psychologist attempting to prepare for a potentially enormous realm of behavioral and human engineering research projects.

Although compromises were required, the goal of an extremely flexible, yet low cost simulator system guided the team throughout the effort.

One of the goals of the development was to make the simulation as realistic as possible, incorporating "virtual reality" techniques such that the experience would include an "inside-out" perspective of self-directed flight through terrain landforms and full head movement for exploration and examination of surrounding features.

Different techniques for inducing virtual reality may be judged on the degree of "immersion" or sense of "presence" each provides. Although these are subjective aspects of the experience and there is no single metric of "immersion" many of the contributing factors have been identified, as shown in Figure 5-1. As shown by the checked items at the right of the figure, we determined that PRISMS could and should incorporate nearly all of the key features necessary for providing a fully immersive experience.

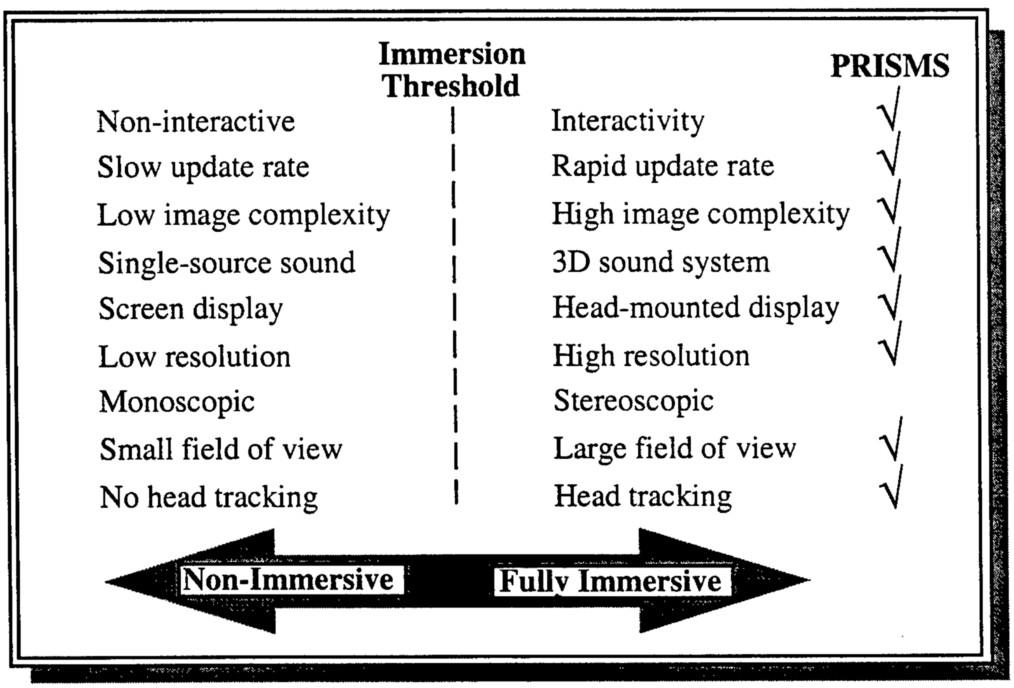


Figure 5-1. Factors influencing the degree of virtual reality immersion with check-marks indicating PRISMS capabilities (adapted from Pimentel & Teixeira, 1993).

Desired Capabilities

Over the course of the project, we continued to expand and flesh out sets of sample experimental scenarios in order to clarify the PRISMS design requirements. The primary requirements categories included (1) a set of selectable simulated flight capabilities ranging from fully automatic to partially constrained, to fully pilot controlled, (2) selectable HMD symbology elements of a broad number of types,

behaviors, and moding structures, grouped and arranged as desired, (3) selectable capabilities for conducting experiments and demonstrations such as "head-down" views of horizontal situation displays or other data, (4) environmental controls (sun, moon, wind, haze, etc.), and (5) target appearance and weaponry applications for use in evaluating situation awareness.

Despite its low cost, we also determined that PRISMS had to provide the capabilities necessary to show HMD symbology in screen-fixed, aircraft-fixed, and earth-fixed frames of reference (described below), along with facilities for symbology demonstration, knowledge acquisition, experimental control, and extensive data recording. In addition, and within cost constraints, many high-end features were to be included, such as a gaming area of realistic terrain, multiple moving targets, photo-textured objects, 3D sound, and voice synthesis and recognition.

In addition to the helicopter cyclic, collective, and pedal controls for full flight control by experienced pilots, it was deemed valuable to permit flight by non-pilots, such as offering flight along a pre-determined path, as if on an "invisible rail," for demonstrations or experiments not requiring aircraft control inputs. Between these two extremes, any level of error constraint could be invokable, such as flight within an "invisible tube" of experimenter-controlled diameter for use in studies employing beginning or intermediate-level pilots.

Physical Configuration

Major Components

The two PRISMS shipping cases contain a cockpit station, an experimenter's station, and an electronics station. The cockpit station includes the pilot's seat, full flight controls, HMD with headphone and microphone, and head-tracking system. The experimenter's station includes a large-screen monitor (with a second monitor optional), keyboard and mouse, four-axis flight control, headphone and microphone, and the symbology management system. The electronics station includes two dual-CPU NT workstations, three OpenGL graphics accelerators, a six-channel audio mixer, a four channel audio amplifier, a full matrix video switching system, and a VGA to NTSC/PAL converter for video recording of PRISMS sessions.

Anthropometric Study

In planning the simulator physical configuration, an anthropometric study was completed to identify the range of dimensions necessary to accommodate test subject pilots and to meet typical control locations relative to human body dimensions. The control positions were adapted from MIL-STD-1333A, Aircrew Station Geometry for Military Aircraft. Although this document assumes seat adjustability, PRISMS was designed to use pedal position adjustability to provide the same anthropometric dimensional range at much lower cost and weight. The reach envelopes for all controls are within the comfortable zones for 5% through 95% male operators.

Figure 5-2. The PRISMS system, nearing completion.

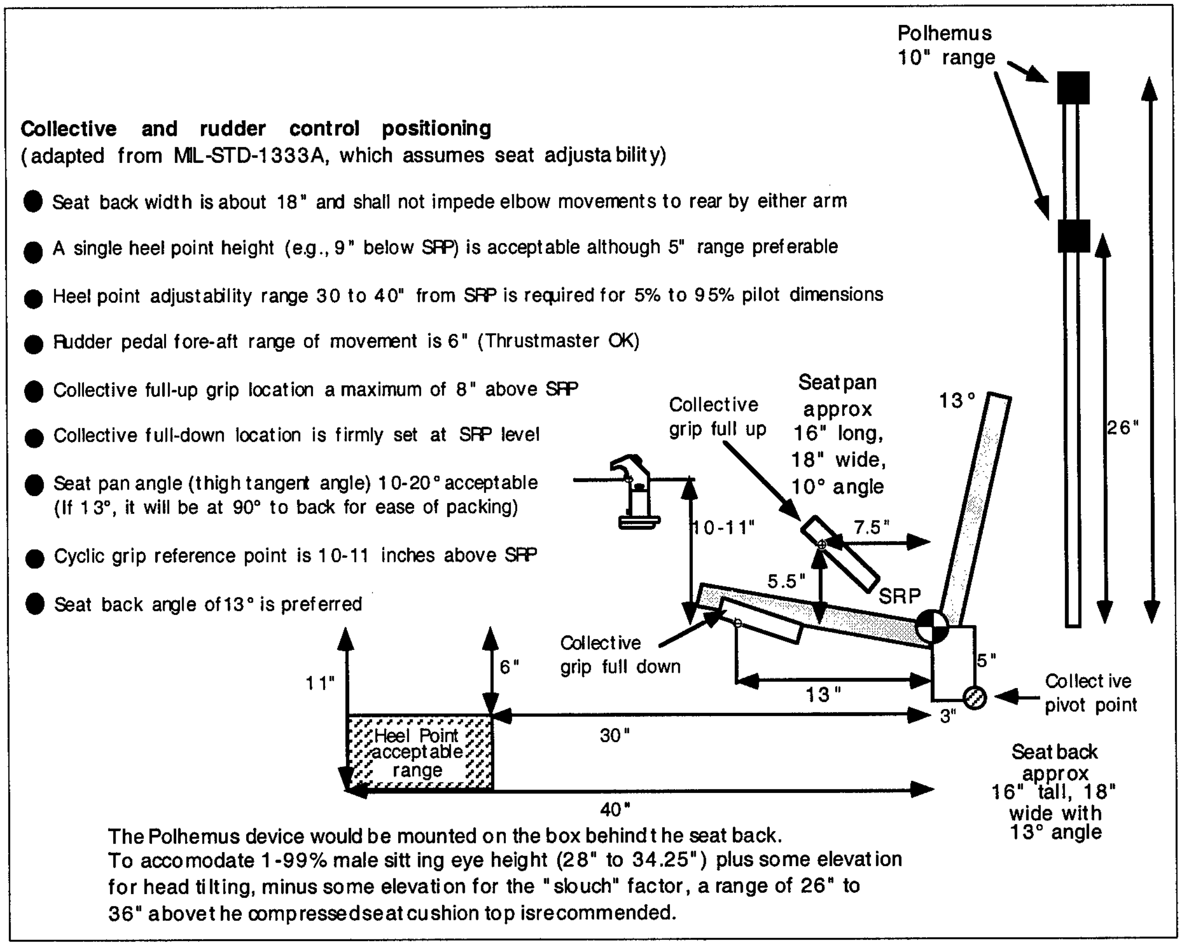


Figure 5-3. Example of anthropometric criteria and dimensions for PRISMS.

Packaging and Transportability

Cockpit design efforts focused on providing a realistic and effective control location geometry for the cyclic, collective, and pedals, while permitting the system to be rapidly packed or unpacked and set up. The design objectives included the use of shipping cases that permit quick access to seat and control mechanisms and storage for the HMD, CPUs, hard disks, and the associated computer components. The test subject's seat itself serves as a storage area in order to save weight and space. The total weight of the two packed cases is now several hundred pounds. This is considerably more than was anticipated at the beginning of the project, but still allows for reasonably convenient transporting to conferences, military facilities, and other meeting sites for clearly communicating symbology behavior and conducting knowledge acquisition sessions with subject-matter experts (SMEs).

Flight Controls

Because the high-end military flight simulation controls were known to cost thousands of dollars each, we selected the best available gaming system hardware. We purchased a set of ThrustMaster controls including the F-16 FLCS Limited

Edition control stick, Weapons Control System (WCS), and the Rudder Control System (RCS). These served respectively as the cyclic, collective, and pedals of the PRISMS simulator.

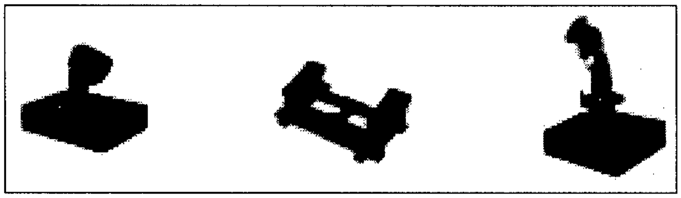


Figure 5-4. The ThrustMaster WCS, RCS, and FLCS.

The six-inch control arm of the WCS was found to be too short for the sensitive collective inputs desired by our pilots, and was modified to approximately 15 inches. Although the modification worked well, the extended lever arm resulted in excessive wear and tear on the lightweight components, so the WCS was replaced by another, very sturdy collective with a stainless steel arm built by Flight Link. This control offers a very smooth twist-grip handle for rpm control, should this be necessary in a simulated aircraft.

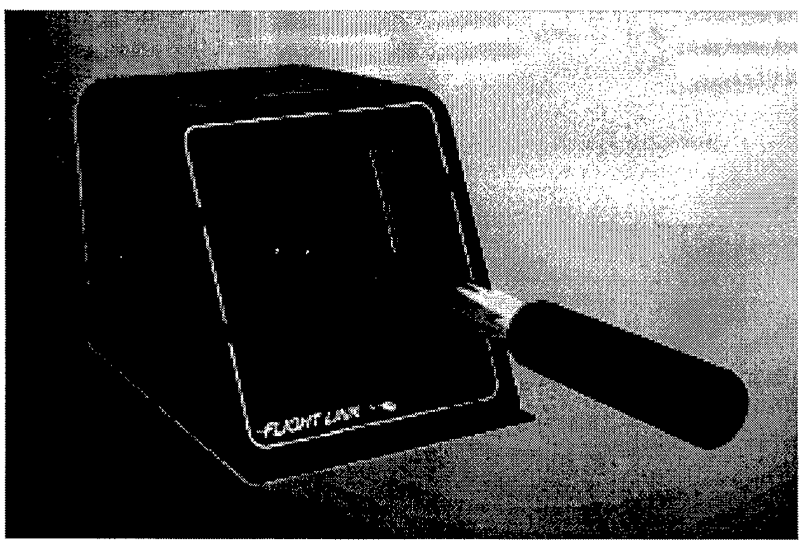


Figure 5-5. The Flight Link helicopter collective control.

The FLCS was found to be quite satisfactory except for the high displacement force requirements. The FLCS was modified to reduce the forces to levels more representative of helicopter controls. New torsion springs were installed, reducing the maximum required forces from nearly 50 pounds to a level just sufficient to return the stick to center position.

Figure 5-6. A close-up showing the FLCS in use as the PRISMS cyclic.

Helmet-Mounted Display Selection

The selection of an HMD for PRISMS use was one of the more difficult issues. First of all, helmets vary across a broad range of parameters including horizontal and vertical field of view, brightness, color capabilities, video formats, pixel size and number, weight, and many other factors. Secondly, the range of costs is quite broad; roughly $1,000 to $120,000. After extensive deliberation, and a visit to Kaiser Electro-Optics in Carlsbad, CA for demonstrations, we arranged to purchase the Kaiser 1000HRpv VIM (Visual Immersion Module) Personal Viewer for use with PRISMS. The VIM provided a 30° vertical by 100° horizontal field of view with four full-color 0.7 in. active matrix LCDs (180,000 pixels per LCD). The VIM was lightweight (26 oz), was eyeglasses compatible, and supported high fidelity stereo sound. The head-tracking was provided by a built-in Polhemus INSIDETRAK system with resolution of 0.03° in orientation.

Figure 5-7. The Kaiser VIM Personal Viewer helmet.

However, some months after placing our order, we were informed by Kaiser Electro-Optics that the VIM helmet was no longer being made. Instead, we were given an opportunity to review the characteristics and costs of the new Pro HMD from Kaiser. Unfortunately, the lowest-priced model offered a field of view of only 18° by 24° -- unsuitable for our purposes. The cost of a Kaiser helmet with a wide field of view similar to the VIM would have exceeded the PRISMS budget.

After an extensive search, we were able to identify an alternative LCD device, the Visette Pro, manufactured by Virtuality and marketed in the USA by nVision. The Visette Pro is very sturdy and reliable, incorporates its own Polhemus Inside-Trak system and provides a 60° by 47° field of view.

Fig 5-8. The Virtuality Visette Pro helmet.

We arranged for a demonstration of the device and were favorably impressed by the quality of the imagery, especially considering the relatively low price, and

ordered a system. Since that time we have also used three of the nVision HMD systems with good effect, including the Datavisor VGA, the Datavisor VGA/HiRes (up to a 78° field of view), and the DatavisorLCD (with a 60° field of view). As we observed the rapid technological and cost changes occurring in the HMD field, we were careful to design PRISMS to permit the use of any HMD.

Head-Tracking

One of the PRISMS goals was to offer an "immersive" approach, providing an effective virtual reality experience for more realistic representation of military rotorcraft tasks. In response to the pilot's control inputs, the PRISMS aircraft altitude, attitude, heading, and speed change as they would in a real helicopter. But the addition of an opaque visor on the HMD and accurate head-tracking fully involves the pilot in the simulation. As the pilot turns his head and shoulders, the field of view moves through the full-surround field of regard and additional portions of the aircraft or the terrain come into view. The effect of being fully surrounded by simulated terrain is enormously more realistic and immersive than peering at a monitor on a desktop. Thus, the goal of immersiveness required an accurate head tracker so that symbology positioning and behavior is appropriately slaved to the user's head movements.

An additional important use of the head-tracker is that of a look-down capability for the HMD imagery that presents images in the cockpit area when the pilot rotates his head downward, as if to look at the console or his lap. Maps, HSDs, other avionics displays, or kneeboard data may be presented to the pilot in this manner. When the experimenter or trainer is developing a new session, various set-up tools may be presented to aid in selection of test parameters. The head-down capability is particularly useful in permitting presentation of any scanned topographic map as a head-down display in the PRISMS cockpit. This addition adds realism to the situation awareness, navigation, or other experimental tasks performable in the simulator. If desired, and appropriate scaling and rectification values are entered, an aircraft present position "bug" could be also be shown on the pilot's map, simulating a digital map system.

Prior to the purchase of the HMD, we used a Polhemus InsideTrak to evaluate it's characteristics and found them quite suitable for PRISMS. When the Visette Pro helmet was purchased, it was furnished complete with an imbedded InsideTrak sensor. The Visette Pro head tracking sensor was calibrated using the latest InsideTrak driver for WorldToolKit under NT 4.0. The unexpected difficulty of the calibration was a frustrating impediment to the accurate integration of the flight model with the HMD field of regard. A number of factors, including the unusual mounting position and angle of the sensor led to the difficulties. Nevertheless, iterative refinements reduced the calibration error to an undetectable level. PRISMS is also designed to use other head-tracking systems such as the Ascension Flock of Birds.

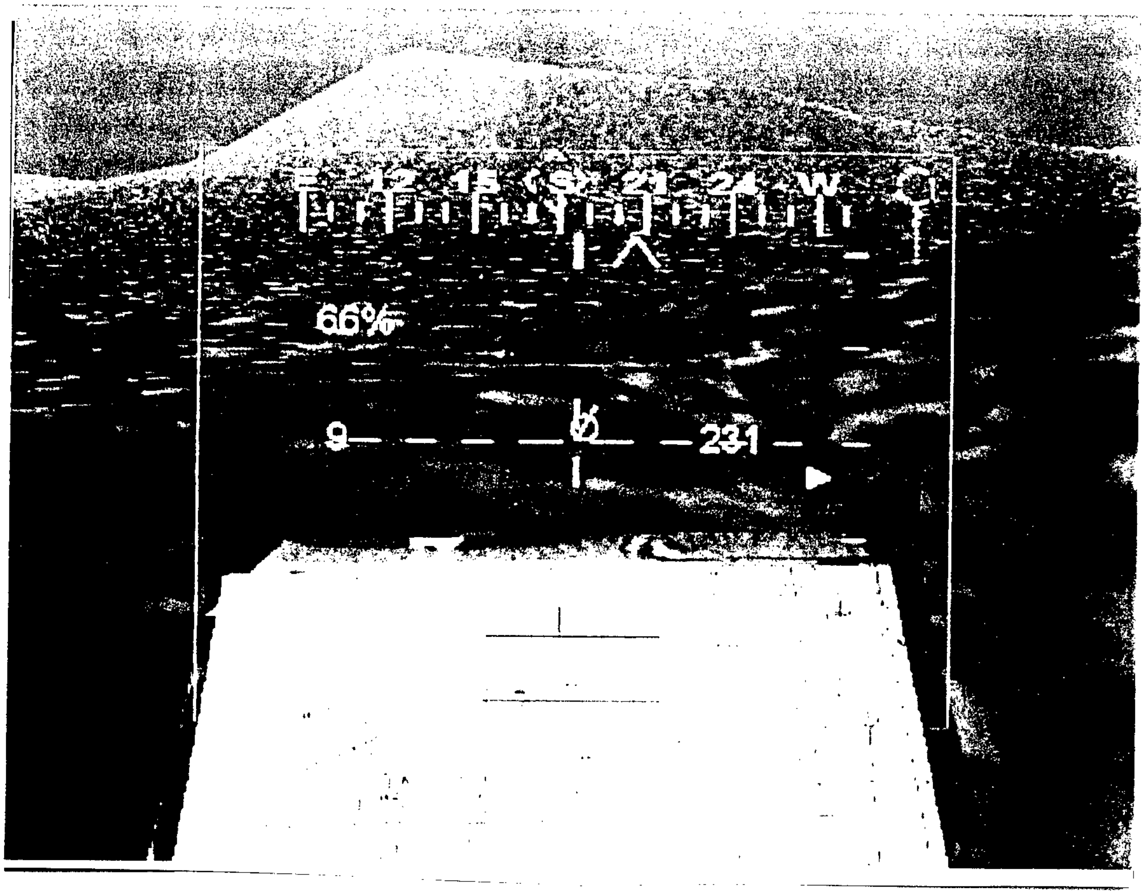


Figure 5-9. The PRISMS HMD view of a map on the aircraft console.

Experimenter Station

As the pilot flies, the experimenter or trainer is able to view several different movable and resizable windows on his monitor. As shown in Figure 5-10, the experimenter can simultaneously observe the pilot's HMD view, maps in various scales with present position indicators, and dialog windows designed for controlling session settings, events, or recordings. This context is similar to flying with the pilot in a test aircraft without the cost or safety concerns usually associated with test flights, and permits discussions of flight symbology during realistic, representative flight operations.

Furthermore, the experimenter or trainer can stop the action, query the pilot on his actions or impressions, and replay a flight sequence after introducing a change in symbology. A series of scenarios can be predefined and linked together to permit a broad variety of tactical situations, aircraft maneuver requirements, and pilot activities in a brief time period. PRISMS is designed for flexibility of application so that individual researchers will find it easy to incorporate and demonstrate a wide variety of symbology ideas and easy to prepare for more formally designed experiments.

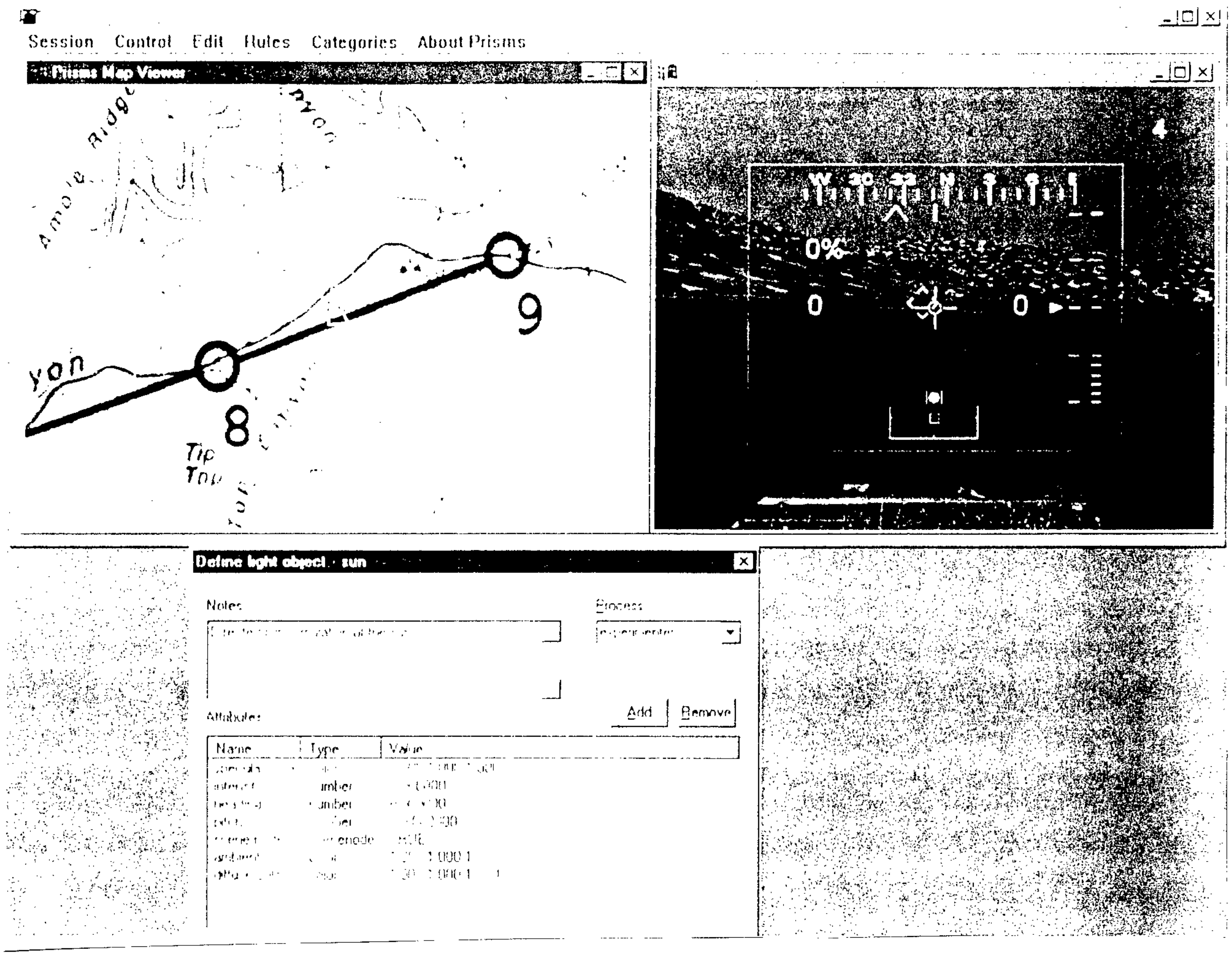


Figure 5-10. An example of windows available on the experimenter's monitor.

A present position "bug" can be displayed on the experimenter's station map, an invaluable aid for monitoring the pilot's progress through the terrain and his current heading and position.

The provision of a second aircraft, controlled with a joystick from the experimenter's station, was undertaken to lend additional realism to an already immersive environment. The second aircraft can be used as a wingman or an enemy aircraft, or simply as another "eye position" to view the exterior of the pilot's aircraft. Object and attribute passing using inter-process communication was implemented to allow each of the two helicopters to update the other's position.

Workstation Processors

PRISMS incorporates two dual CPU NT workstations. The Intergraph TDZ 2000 was tested at its introduction at COMDEX in 1998. The tests showed that it would approximately triple the simulation frame rates we had previously achieved in the pilot's station. Depending upon the terrain models visible and the density of the vegetation texture, the frame rate ranges as high as 70 Hz. Frames rates are

dependent upon a number of factors such as the extent of terrain visible (number of model areas depicted), the types of vegetation codes presented, and the number of symbol elements shown.

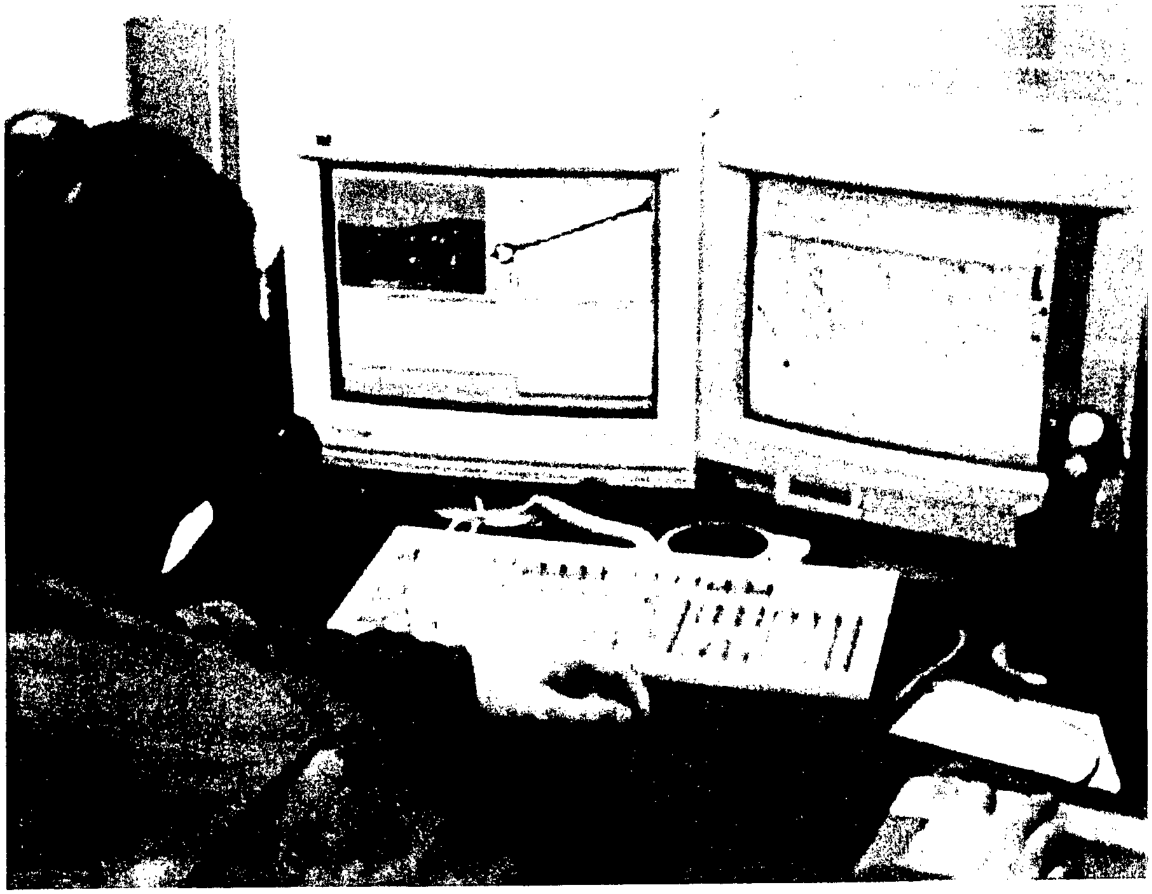


Figure 5-11. A view of the PRISMS experimenter's station.

Any system can be "brought to its knees" by increasing the density of the presentation until frame rates fall below acceptable levels. For this reason, the PRISMS interface permits the experimenter to make the appropriate trade-offs. For example, a linear symbol "draping" algorithm was devised giving the experimenter indirect control over the number of points used to describe lines drawn on the terrain, trading off line precision against acceptable frame rate.

Software

Flight Model

Although various flight models are commercially available, we elected to develop our own. Although a difficult decision, it permitted us to maintain control over the model's complexity and the resulting impact on video frame rate. Furthermore, it assured that we would have direct control over variables such as thrust, power, mass, velocity, drag, torque, angular velocities and moments of inertia, relative wind moments, and trim adjustments,. Iterative qualitative

evaluations of aircraft handling during flight through the New Mexico database were conducted by the authors, as well as Army helicopter pilots with very satisfying results and continual improvements to the fidelity of the aerodynamic simulation.

During the summer of 1997, Loran Haworth, the Project COTR and Gene Kasper, the Alternate Project COTR visited ThoughtWave headquarters in Torrance California. A briefing was provided on the planned capabilities of the PRISMS simulator, and demonstrations of the system symbology, terrain presentation techniques, and helicopter flight control model. Both the COTR and ACOTR were given opportunities to "fly" through simulated mountainous terrain in New Mexico, using the flight controls and the HMD with Apache symbology. They provided us with a number of useful recommendations such as reducing the cyclic forces and introducing some stability augmentation or autopilot functions to reduce pilot workload.

Our Apache SME, Mike Couch, provided an interim evaluation of the PRISMS simulator handling over the course of three days at the ThoughtWave offices. A primary objective of these trials was to maximize the similarity of the PRISMS handling to that of the AH-64. In enhancing the PRISMS flight model based on the SME's suggestions, improvements to the handling qualities were made as quickly as possible, so that several iterations could be completed in the time available. In conducting these activities, the payoff of having of developed our own flight model was most evident. SME comments about handling qualities could usually be directly related to factors such as mass or drag and corrections could be made accordingly.

A view of the SME in the PRISMS cockpit station is shown in Figure 5-12. The cyclic and pedal controls are visible, as is the HMD and head tracker. Components of the experimenter's station are shown in the background.

Among the adjustments to the flight model were increasing the tendency of the helicopter nose to remain in the direction of flight and making the overall handling qualities more forgiving and smooth. Loran Haworth again visited the ThoughtWave facility on the spring of 1998 in order to review the progress of the project, test the new flight controls and handling qualities of PRISMS, and observe the recently introduced symbols and second helicopter capability.

Although PRISMS currently is configured to have flight handling characteristics similar to the AH-64 Apache, it is important to recognize that the flexible flight model easily permits simulation of other helicopters. Fixed-wing simulation or ground vehicle simulation are also possible with relatively few changes.

Symbology and Frames of Reference

Because Apache pilots form the available pool of attack helicopter SMEs, we have constructed a complete set of symbols from the AH-64 Integrated Helmet and Display Sighting System (IHADSS) as a baseline to which other symbols may be added. Complete descriptions of these symbols, their purposes, and their behaviors

are provided in our Phase I final report (Rogers, Spiker, & Asbury, 1996). In addition, PRISMS provides a set of tools for easily defining new symbols and their appearances, behaviors, and the rules for their presentation or removal from the current symbol set. PRISMS is also designed to permit the use of any of three different "frames of reference," as described below.

Figure 5-12. Apache pilot testing the PRISMS flight model.

In order to effectively describe and control the behavior of HMD symbols, three different frames of reference must be considered. First, symbols may be "screen-fixed," as if painted on the helmet visor, so that they are always in the same position relative to the pilot's field of view. Nearly all of the Apache symbols are of this sort. Second, other symbols may be "aircraft-fixed," in that the symbol is moved or rotated to compensate for head movements and stay in the same position relative to the aircraft itself. The Apache has one (diamond-shaped) symbol that behaves in

this manner. It is called the "head-tracker" and is used to show the relative position of the aircraft nose.

Third, symbols may be "earth-fixed," in that the symbol is moved or rotated to compensate for both pilot head motion and aircraft motion, so that the symbols appear to be located on or above positions in the real-world terrain. No earth-fixed symbols are currently included in the Apache. Flight simulator studies of these earth-fixed, or "conformal" HMD symbols have rarely been published in the open literature. One such study is that of Haworth and Seery (1992). Because the earth-fixed symbols are likely to have a major role in the next generation of HMD symbology, PRISMS was specifically designed to support their simulation.

Digital Terrain Data Availability

Although we had initially anticipated developing our own terrain database using USGS or other digital terrain elevation data (DTED) and digital feature analysis data (DFAD), we learned of the progress of the South West USA (SWUSA) database from work on another project. Discussions were then held with the Data Base Generation System (DBGS) group of Lockheed-Martin at the 58th Training Support Squadron at Kirtland AFB in Albuquerque (supporting mission preview simulation). The discussions focused on the possibility of acquiring this highly enhanced DMA data for a large area in New Mexico. Although it was determined that acquisition of the data would be possible for this project, it seemed unlikely that the PRISMS processing power would permit effective use of the data in a moving scene. Thus, we continued to plan to use USGS data, successively adding gradual textural enhancements to minimize performance degradation.

Some months later, we obtained a Multigen OpenFlight terrain database depicting the Hunter-Liggett, California area with full texturing and high fidelity cultural feature models representing the airfield area. Because the Hunter-Liggett data was believed to be similar to the Lockheed-Martin SWUSA data we were surprised to find that we were able to "fly" though the area using head tracked control, while viewing the terrain on a monitor. Although our original estimates suggested that the processing power requirements for use of the SWUSA data were too great for PRISMS, we subsequently determined that this enormous database (240,000 square miles of New Mexico terrain) could indeed be employed.

The PRISMS geographic location mechanisms employed with the SWUSA data base were designed to include both latitude-longitude and UTM coordinate systems. These mechanisms permit the selection of flight areas during an experimental session, the definition of specific positions such as waypoints, and the scoring of flight performance precision. The accuracies of the mechanisms were repeatedly evaluated through analytical comparisons with USGS paper map coordinate and elevation data. The coordinates of prominent terrain features in mountainous portions of the New Mexico terrain were identified from USGS 1:24,000-scale paper maps. The coordinates were input to PRISMS and the accuracy of the generation of resulting views were evaluated through map-terrain analysis.

Metrics

As we began to recognize the broad range of potential applications of the PRISMS simulator, we made a concerted effort to include all of the tools the research community might require. A literature review was undertaken to identify the most important experimental methods and metrics, so that the necessary tools for each type of research would be made available. A primary objective of the interface design effort has been to permit the experimenter to choose and implement sophisticated metrics in the dialog without any requirement for additional software programming.

PRISMS was designed to incorporate a range of selectable performance measurements including (1) root mean square error (RMSE) from a designated flight path, altitude, or airspeed, (2) accuracy of HMD reticle placement on a specified feature in the terrain, (3) response time for target detection and accuracy of target engagement, (4) total time of intervisibility with a known enemy position, (5) waypoint crossing accuracy, (6) precise position landing accuracy, and (7) evaluating pilot skills with aircraft maneuvers such as the Aeronautical Design Standard (ADS-33) "pirouette" with measures of altitude, heading, and distance errors.

In addition to these built-in measurement options, provisions have been made to ensure the ease of creating new metrics as needed by the experimenter or trainer. For example, some new PRISMS metrics were needed to support the experiments conducted with the Apache pilots. The dialog structure, with its provisions for creating rules, expressions, and operations, was used to construct rules that would start and stop timers for measuring head azimuth dwell times in nine segments of the forward 180°.

User Interface

A large portion of the system design activities was directed at user interface development. One of the primary objectives for PRISMS was that this powerful system be easily operable without need for sophisticated programming skills. Because the system is very versatile and the potential users may have countless ideas for demonstrations and experiments, great flexibility was required of the dialog. The challenge was in devising a dialog that could provide this flexibility without adversely impacting its ease of use.

In addition to frequent telephone discussions, many extended meetings were held at ThoughtWave and Anacapa facilities for firming up the philosophy for the experimenter-computer dialog structures. The design philosophy has attempted to balance an almost open-ended range of PRISMS capabilities with easy-to-use features for constructing and conducting experiments and demonstrations.

The initial intent in the development of the PRISMS dialog was to provide a broad range of powerful simulation and experimentation capabilities yet make the interface so intuitive and forgiving that it would require only pointing and clicking on button selectors, check-boxes, and entering a few text and numeric items.

However, as the PRISMS system capabilities grew, the number of possible selections made such an interface unwieldy. Finally, with the decision to allow the PRISMS user to construct essentially any type of tasks, conditions, and metrics, the notion of a simple, unchanging graphic interface became wholly inapplicable. Instead, what was required was a more powerful, expandable dialog approach that could nevertheless be quickly mastered by a researcher without formal training in programming.

It also became apparent to us that the interface should include multiple levels of user interaction. At the highest level, a user-friendly interface should permit the selection of parameters for most experimental requirements, such as choosing the HMD symbols to be included and basic metrics to be employed. A series of pop-up and pull-down menus and screens has been designed to permit the experimenter to define the characteristics of an experiment or demonstration including objects in the terrain, flight plans, lighting, aircraft model constraints, auxiliary displays, HMD symbol types, performance measurement techniques, and a variety of other parameters. For example, Figure 5-13 shows the pop-up screen used for defining the nature of the simulated sunlight falling on the terrain.

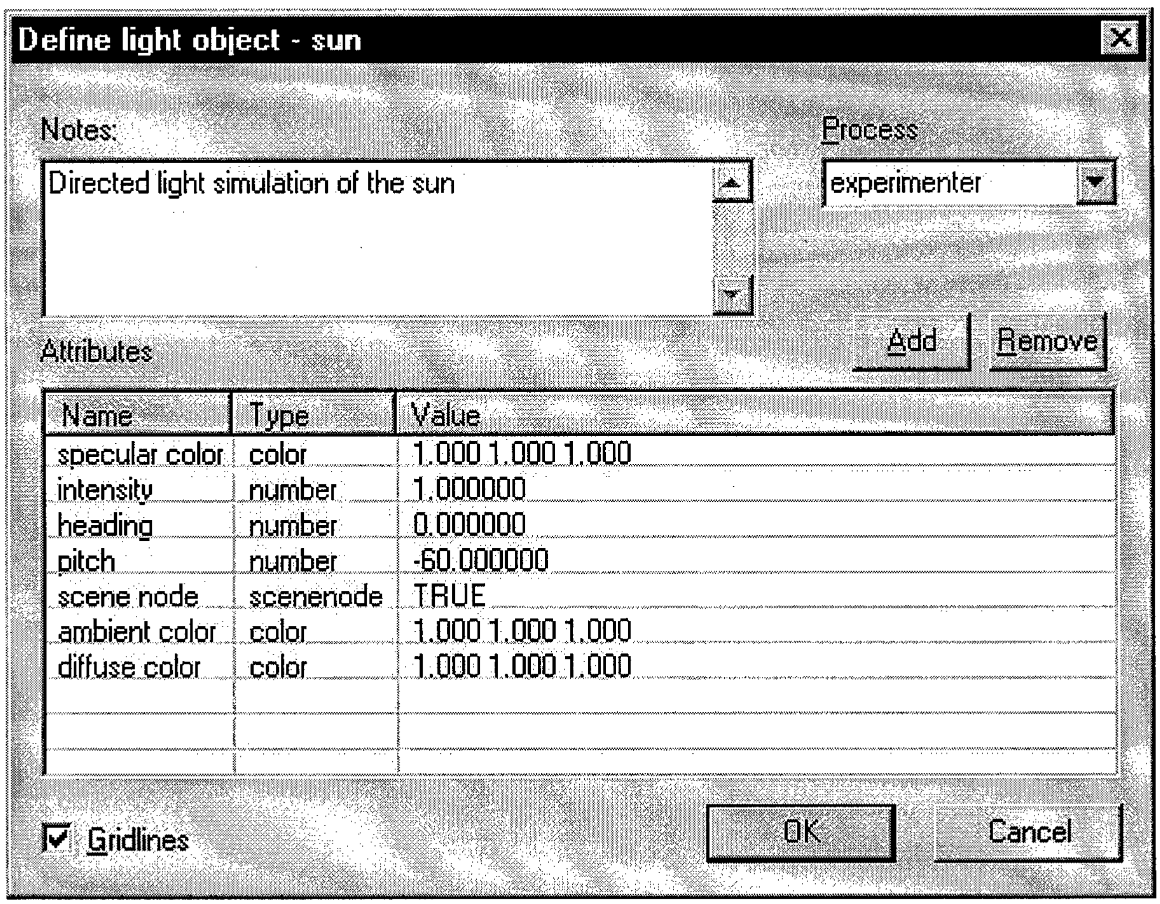


Figure 5-13. PRISMS dialog page for defining the sun simulation.

Although we attempted to create comprehensive high-level interfaces, we recognized that the research community is an inventive one, and may create entirely new methodologies. To support these advances, we provided a second level of user interaction with a set of "tools" for building new experimental paradigms, metrics, and symbol characteristics without a requirement for programming skills.

The result was a rule-based system with which the user specifies that *if* certain conditions exist, *then* certain events will take place. Formalizing some rule statements is easy, and for some it is a challenging task. First of all, it is necessary to determine how the knowledge should be described. In the domain of expert systems, things are typically described as belonging to three categories: *objects, attributes,* and *values*.

Objects can be concrete, such as "animals," or conceptual, such as "hygiene." Figure 5-14 shows an example (adapted from Harmon & Sawyer, 1990) of an object that has attributes. The attributes can take on different values. The values can be thought of as selections from a list. Thus, "body covering" might be "feathers," "fur," "scales," "skin," and so forth.

It should be noted that deciding what is an "object," or an "attribute" or a "value" is one of the more intriguing tasks in knowledge engineering projects. Selecting the best levels of abstraction and grouping the values within attributes generally requires careful evaluation and, sometimes, repeated attempts. For the purposes of this project, objects are usually (but not always) major components such as "the helicopter" and have attributes such as "airspeed" and "altitude" which in turn have values such as "40 knots" and "50 feet"

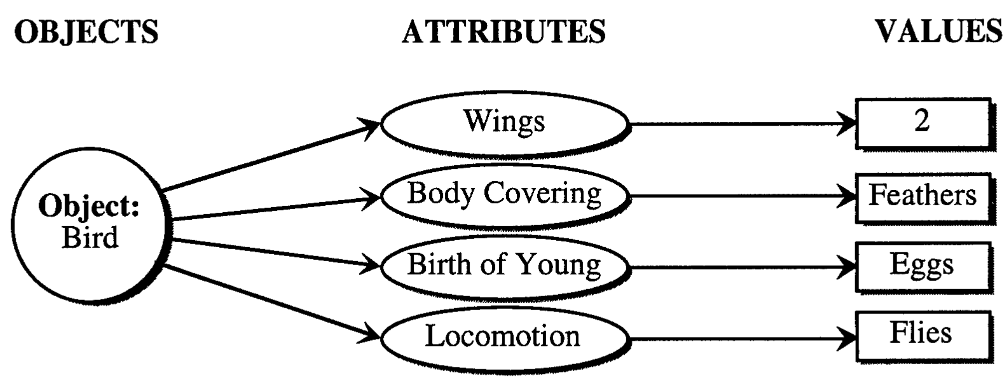


Figure 5-14. A diagram of an object with attributes and values.

The objects and attributes already included in the PRISMS system may be all that many users ever need. The addition of new objects and attributes, however, is a straightforward task and is aided by the PRISMS dialog system itself. A dialog page summarizing a few of the hundreds of PRISMS objects is shown in Figure 5-15. Column 1 presents the object names, Column 2 the attribute name, Column 3 the attribute type, and Column 4 the current attribute value.

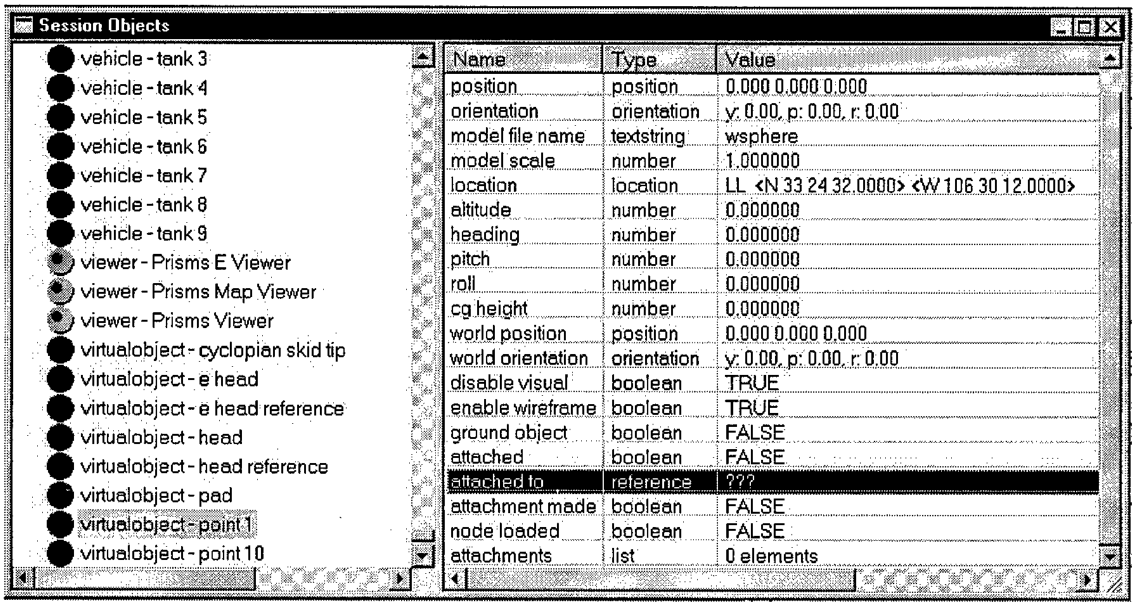


Figure 5-15. Sample of objects used in one PRISMS test session.

The dialog design has attempted to foresee a number of experimenter task requirements and provide assistance through special, user-controlled windows that may be displayed during the construction or conduct of an experiment. For example, the experimenter may wish to observe the changing values of some particular attributes in order to control various events during the simulation (such as the sudden appearance of an enemy vehicle). For such requirements, the PRISMS dialog includes an "Attribute Watch" window, as shown in Figure 5-16. The experimenter can move the window to a corner of his screen and add as many attributes as desired for monitoring purposes.

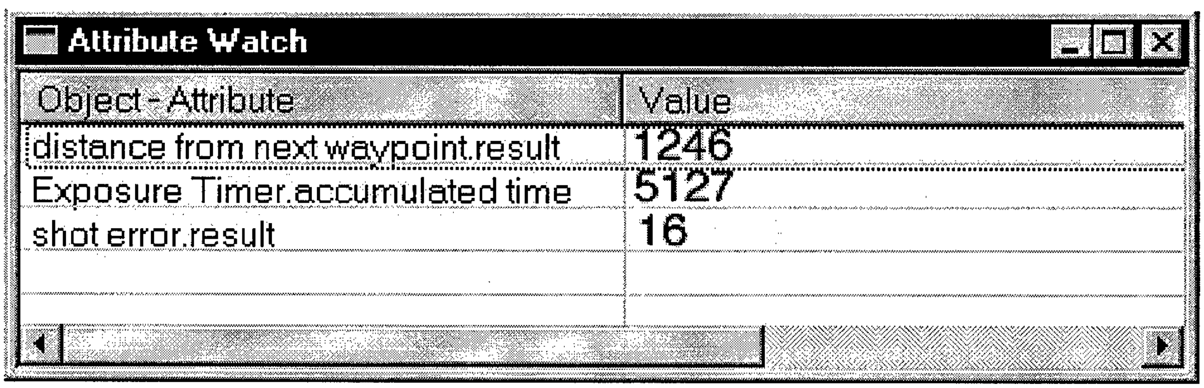


Figure 5-16. The Attribute Watch window for monitoring changing values.

Once the necessary objects, attributes, and values have been identified, inferential relationships can be stated in the form of rules. A rule uses an IF clause to identify one or more conditions that must be satisfied, and a THEN clause to indicate the inference. Both the IF and THEN clauses are stated using a mix of objects, attributes, and values.

Thus, at this second level of user interaction, a unique logical dialog is provided so that the user can easily set up an infinite variety of special task requirements or performance metrics such as "record elapsed time between Waypoint 7 crossing and designation of Target 3 unless altitude is greater than 200 ft." This development of this dialog structure was a significant system design achievement and was critical to meeting the project objectives. The third level of interaction is the programming level, required only for major system changes that could not be anticipated.

Sample experiments were devised to test the operation of the higher level dialogs, and were repeatedly generated throughout the period of the project so that the dialogs would continue to be enhanced both in power and ease of use. Each time a set of sample experiments was devised, fewer and fewer incremental improvements to the dialog were needed. The specific techniques for creating objects, attributes, values, rules and HMD symbology are fully described in the PRISMS User Manual.

PRISMS Sound and Video Systems

PRISMS includes a six-channel audio mixer and four-channel audio amplifier for isolated communication between pilot and experimenter, input of helicopter and weapon sounds, 3D sounds, voice synthesis, distribution to NTSC output for video, external speakers. Full matrix video switching and VGA to NTSC/PAL video converter has been provided, permitting routing any of three graphics channels to any of four output channels (experimenter's monitors, subject helmet, and NTSC video).

A 3D sound generation has been implemented making it possible to produce sounds such that they appear to the pilot to be attached to a position in space or on the ground, regardless of the pilot's own head movements. These sounds may be used as desired by future researchers, perhaps evaluating the utility of a wingman "beep," the positions and actions of enemy weapons systems, or spatial separation of incoming radio messages.

PRISMS voice recognition and synthesis systems have been implemented, permitting pilots to use voice commands for changing symbology sets or any other purposes. The experimenter may also use voice commands for control of experimental parameters. The voice synthesis system can be used with rule-based methods for use in presenting voice warnings such as used with the APR-39 warning system, or for other cockpit alerts.

Section 6: Symbology Evaluations with PRISMS; Experimental Method and Metrics

Introduction

Having conducted the information requirements analyses and developed the PRISMS simulator, we were in a position to begin conducting hundreds of studies of new HMD symbology. Unfortunately, only a few of these could be undertaken within the time and resources available and we were faced with restricting our research effort to a small fraction of that possible. Thus, we attempted to identify the new symbols that were likely to provide the highest payoff based on our knowledge of the operational requirements and current shortcomings. In doing so, we consulted our analytical data as well as our subject matter experts. The most important symbols were included as independent variables in our experiment, and the runners-up were evaluated by flight demonstrations on PRISMS, followed by interview sessions.

The Attack Mission Experiment

In structuring these data-gathering techniques, we attempted to make the best trade-off between experimental control and realistic mission relevance, pretesting our methods with expert pilots. We also selected research topics to demonstrate the breadth of PRISMS' capabilities for symbol development, performance measurement, and flexibility in adding and modifying study session features and characteristics.

This section of the report describes the experimental and demonstration sessions in detail. The experiment is discussed in terms of the necessary preparations, participants, apparatus, procedures, experimental design, and the results of 13 experimental comparisons.

Method

Participants

We initially made arrangements for an August 1998 visit to interview Apache Instructor Pilots at Fort Rucker. Unfortunately, because of subsequent computer failures leading to unavoidable slips in the Air Warrior test schedule, we were notified that no pilots could be made available for our work. We then contacted Lt. Col Michael Jensen, Commander, 1st Battalion (Attack), 211th Aviation Regiment, of West Jordan, Utah. Lt.Col Jensen graciously arranged for our visit there in late September, 1998, where 14 Apache pilots participated in a series of simulated flights to gather data on the new HMD symbology and symbology moding strategies.

Their average number of helicopter flight hours was 2,368 (range 700-7800) and their average number of hours in the AH-64 was 1,090 (range 380-3000). The pilots were advised that the purpose of the study was to evaluate potential new HMD

symbols in the light of operational requirements and that they would fly the PRISMS simulator with and without the new symbols in order to gather data and facilitate discussions about symbol utility and rules for effective presentation of the symbol in the HMD. They were also told that individual sources of opinions would remain confidential.

Apparatus and Materials

Terrain areas selected. The terrain selected for the experiment was located in south-central New Mexico in an area with mixed vertical development ranging from flat desert to low hills to mountains about 3,000 feet above the desert floor. The specific area used for the familiarization flight is found on the USGS 1:100,000-scale map entitled "Tularosa," showing Rhodes Canyon passing through the San Andres Mountains. A portion of this topographic map is shown in Figure 6-1.

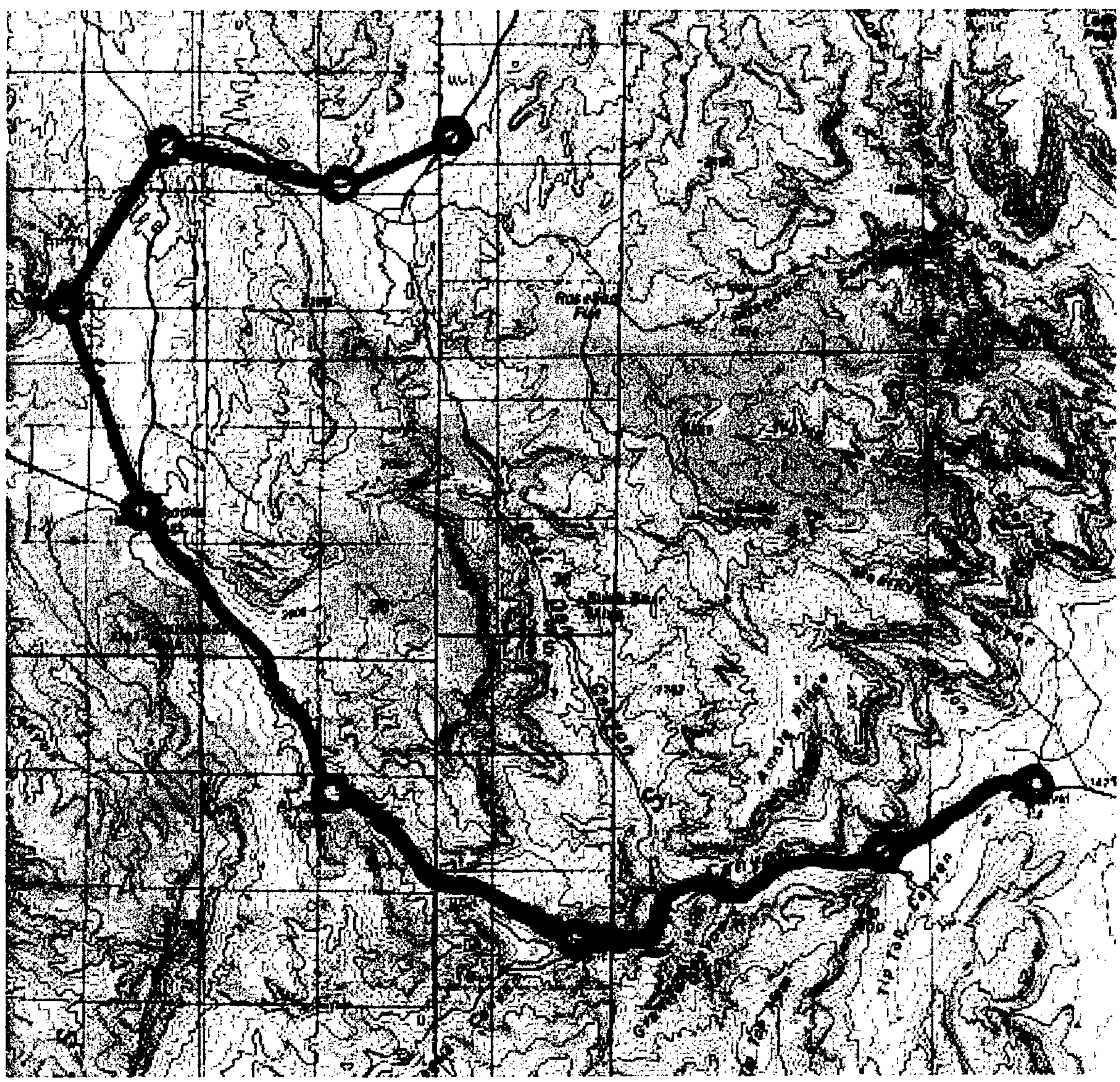


Figure 6-1. Topographic map of the familiarization flight area.

The route through Rhodes Canyon was chosen for familiarization because its dramatic and easily distinguishable features as well as the requirement for frequent heading and altitude changes to closely follow the bottom of the canyon.

The area selected for the experiment was just north of the familiarization area and is shown on the USGS 1:24,000-scale 7.5 x 7.5 minute quadrangle map entitled "Fairview Mountain." The terrain in the southeast portion of this map sheet provided nearly ideal landforms for a helicopter attack mission, including cover and concealment along the route, good battle positions behind a ridgeline masking the BPs from the enemy armor column, and a large hill to the rear of the BPs so that the aircraft would not be "sky-lined" during the bob-up maneuver. A copy of a portion of this map is presented in Figure 6-2.

Procedure

Familiarization flight. The pilots were told that they would have an opportunity to get the feel of the PRISMS handling characteristics by doing a hover and landing on a pad, and then flying down a canyon. They were also shown a drawing of the virtual waypoint symbol as it would appear later in the flight, and a screen image of a tank that would appear in the terrain as a "target of opportunity" to be fired on. Subjects then donned the helmet, adjusted the inter-pupilary distance and individual eye focus and sat motionless for a few seconds to complete head-tracker calibration. The three controls buttons on the cyclic grip (trigger, symbol mode switch, and map-stepping switch) were indicated to the pilot, and the pilot was requested to cycle through the four symbol modes as well as the various head-down map views. Pilots were instructed to fly at about 100 feet and 60 knots. During the familiarization flight, which lasted about ten minutes, the experimenter pointed out how the command heading cue could be used to find waypoints, and later, how the white "lollipop" waypoint symbol could be used to identify waypoint positions in the terrain. It was also explained that if the next waypoint position was obscured by terrain between it and the aircraft position, it would be shown by a dashed red outline. Two "targets of opportunity" (tanks) were pointed out by the experimenter, and fired upon by the pilots.

Experimental tasks - unaided. The pilots were instructed to examine a 1:24,000-scale paper map of the area of operations complete with a attack mission plan overlay and drawing of the EA. They were reminded of the head-down map visible in the helmet and told that it would display a series of overlapping portions of the route shown in the paper map. They were told that they were to overfly all of the waypoints and that the map and the command heading caret in the magnetic heading scale would be their only navigation aids. They were further instructed to maintain 100 feet AGL altitude and a 60 knot airspeed, to detect and fire on targets of opportunity, and to land at the Holding Area (HA) at Waypoint 5.

After landing at the HA, the pilots were instructed to examine the HMD map segment showing the path to the BPs and that they should fly to and land at the center BP, where the Command Heading Marker would lead them. They were instructed to proceed at approximately 40 knots, to maintain masking from the

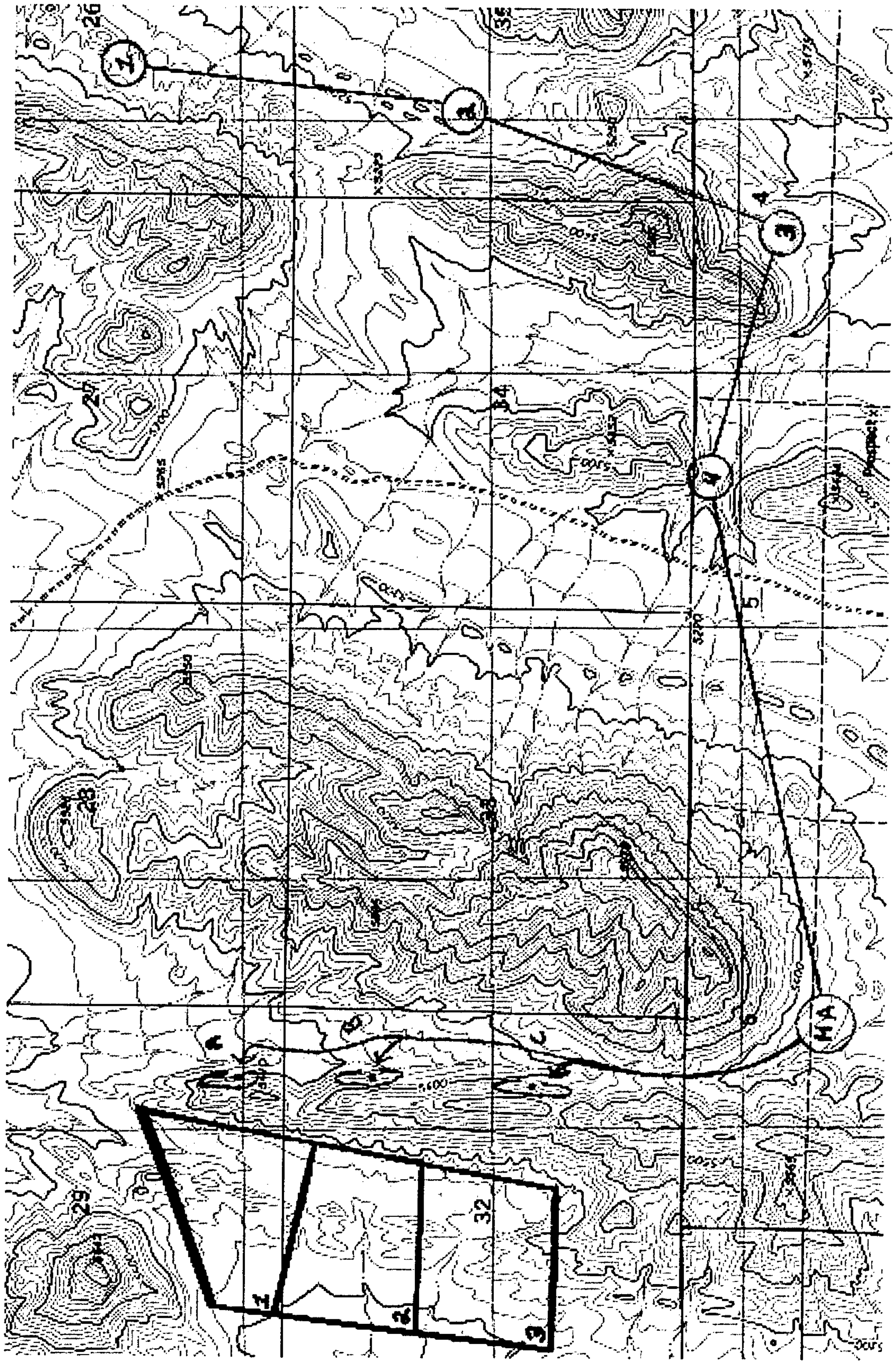


Figure 6-2. A part of the topographic map of the experimental area.

enemy positions to the west, and to land at the BP as accurately as possible. After landing at the BP, the pilots were instructed to look at the HMD map segment showing the EA in its entirety and to observe the three firing sectors. They were told that upon bob-up that they would see a column of enemy tanks (16 tanks were visible) and that they were to fire on only two tanks: the one closest to the left boundary of the center sector and the one closest to the right boundary of the center sector. They were urged to fire within 15 seconds and then bob down to the BP.

Experimental tasks - aided. In all cases, the aided tasks were performed after the unaided tasks. After a rest period of about two minutes, the pilots were instructed that the next condition would be the same as the previous one except that they would be aided by the virtual waypoint markers, or "lollipops" along the route. They were also told that when they closely approached the waypoints, they could see a 10-foot hemisphere marking the exact spot on the ground, as shown in Figure 6-3. These hemispheres could be used to aid accurate landings at the HA and the BP, especially if the aircraft had overflown the waypoint and the waypoint marker had jumped to the next waypoint. The rest of the instructions were identical to those of the unaided condition.

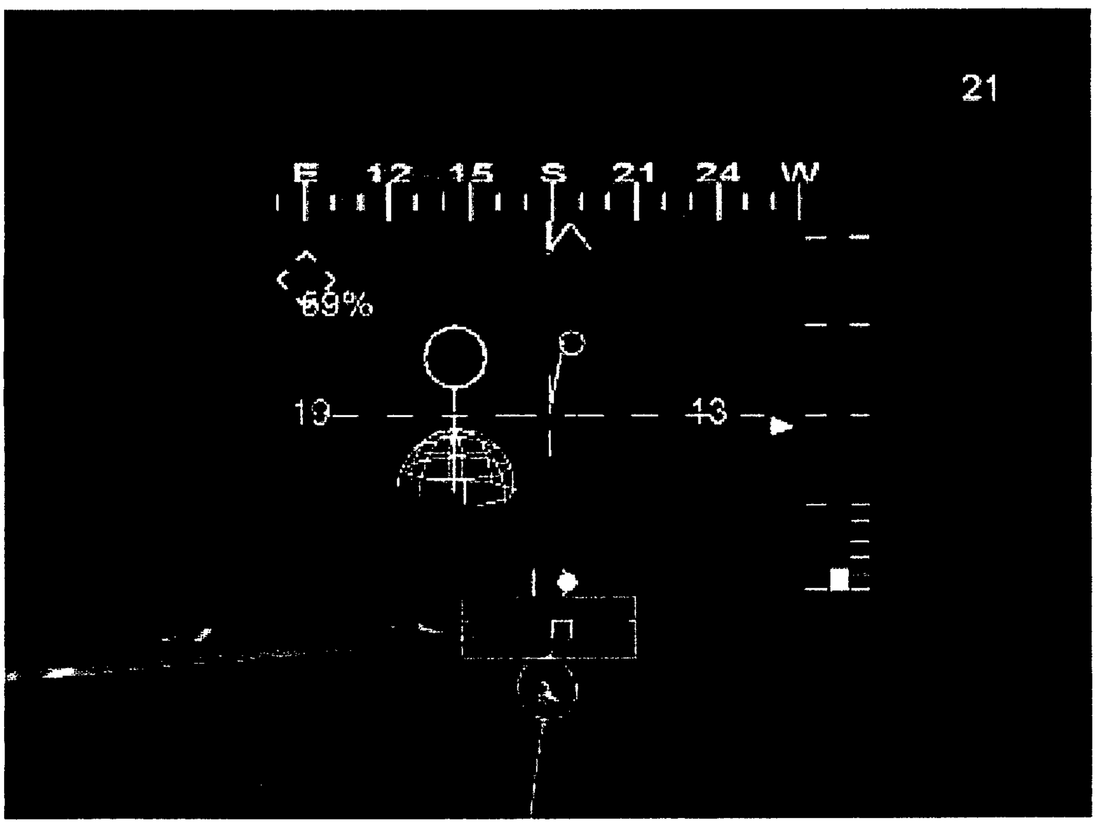


Figure 6-3. Examples of the "lollipop" and "igloo" waypoint markers.

After landing at the HA in the aided condition, the pilots were instructed that in addition to the BP marker, they would see the EA marked out with red lines in the terrain and that if the aircraft was masked from the EA, the red lines would

appear as dashed lines. Figure 6-4 shows the appearance of the EA from the south, near the HA. In this example, the aircraft is at an altitude of 489 feet above ground level, and clearly exposed to the enemy forces.

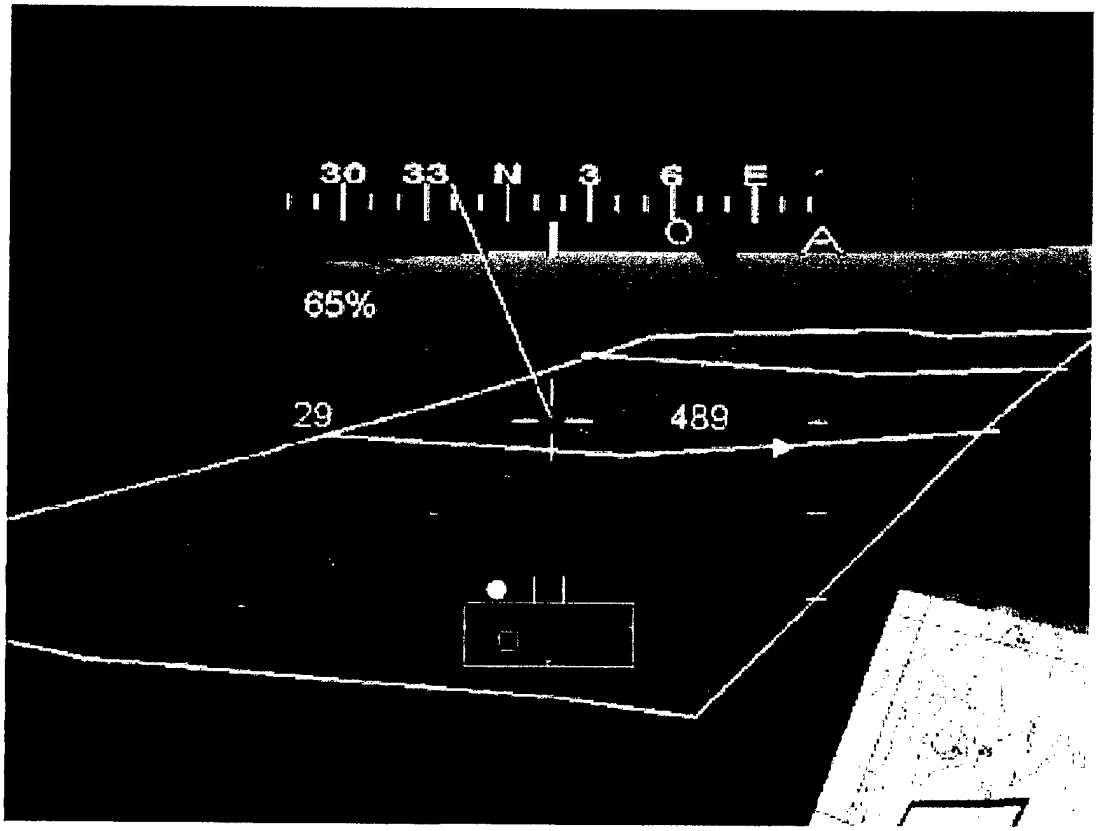


Figure 6-4. View of the virtual EA marker symbol from the south.

Upon landing at the BP in the aided condition, the pilots received the same instructions as in the unaided condition, except they were told that they would be able to see the EA in the terrain and should shoot the two tanks nearest the lines marking the left and right boundaries of the center sector.

Figures 6-5 and 6-6 show the pilots view of the EA symbology as it is seen from the BP. Figure 6-5 shows an example of the dotted lines of the symbol becoming solid as the aircraft rises from a masked position behind the ridgeline. Figure 6-6 shows the appearance of the assigned central section of the EA viewed from above the BP.

Experimental Design

Independent variables. The only independent variable was the presence or absence of the earth-fixed HMD symbology marking the waypoints and the EA boundaries. To control for the very large range of individual differences in performance, a repeated measures design was selected in which each subject flew both the unaided and then the aided conditions. During the first flight through the mission area, the pilots received no feedback from the experimenters regarding the

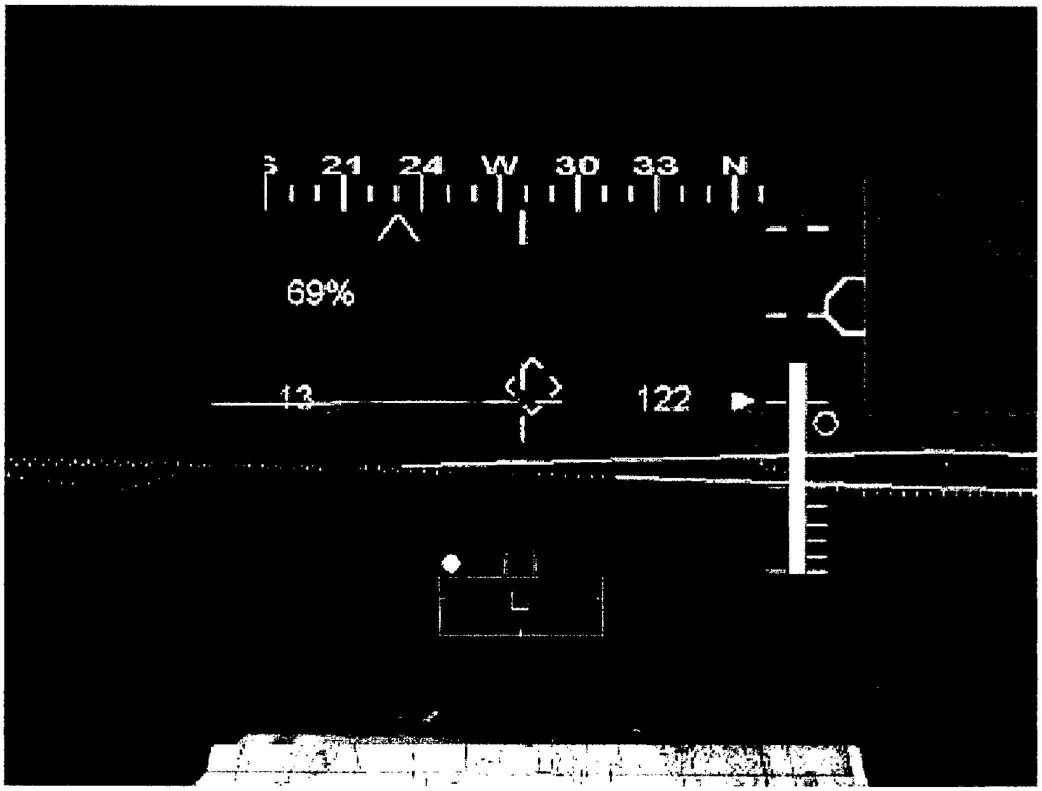


Figure 6-5. Partially masked view of the EA from the BP.

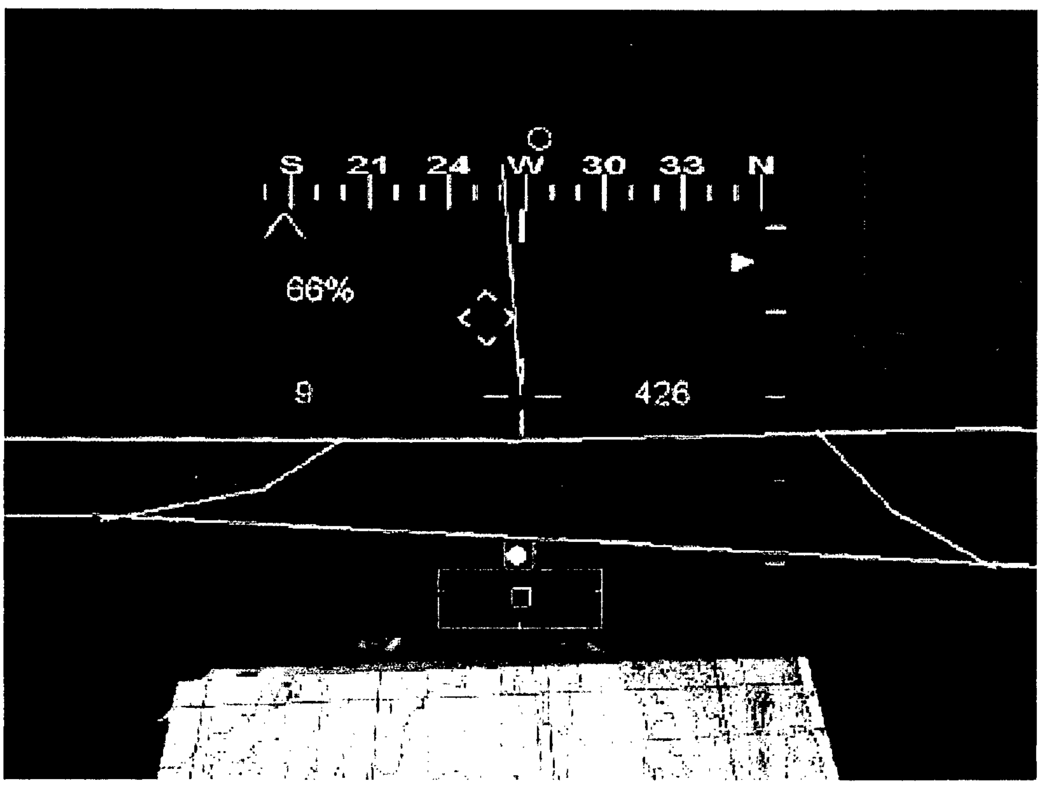


Figure 6-6. Direct view of the central section of the EA from the BP.

accuracy of their waypoint crossings, landings, shots at the EA, or on any of the other performance metrics. During the second flight, the earth fixed symbols provided the pilots with direct feedback on their performance accuracy.

Dependent variables. The earth-fixed symbology was expected to greatly reduce pilot workload in the navigation tasks and increase situation awareness. Because performance measurements are not always clearly related to these improvements, a number of different metrics were employed in attempting to identify enhanced performance. These included the accuracy of waypoint passage (feet), the number of targets of opportunity detected (number fired upon), the landing distances from the HA and BP (feet), the accuracy of altitude maintenance (RMSE feet), the accuracy of airspeed maintenance (RMSE feet), the total exposure time to the EA enroute (seconds), the total number of exposure events, the total exposure time during the bob-up (seconds), the number of inadvertent ground contacts, the accuracy of target selection in the EA (feet), and the time (seconds) that the head angle fell within each of nine 20-degree sectors in the frontal 180° field of regard for each flight leg.

Subjective data. In addition to the performance measures described above, after the aided condition was completed, the pilots were requested to estimate the work-load reduction percentage resulting from the presence of the waypoint markers and also from the presence of the EA sector lines. As an extension to these estimates, they were queried regarding the perceived utility of the earth-fixed symbols, their suggestions for improving them, and their recommendations for the conditions under which these symbols should appear and disappear from the symbology set.

Results

Data Analysis

Accuracy of waypoint passage. The accuracy of waypoint passage (the sum of passage distances for Waypoints 1 to 4, the HA, and the BP), was significantly better for the aided group, $t(13) = 7.276$, $p<.001$, with a mean distance of 878 feet (SD = 373) vs. 287 feet (SD = 215). Every pilot in the study was considerably more accurate with the earth-fixed aids to waypoint recognition than without them. The relative difference between unaided and aided conditions was consistent across all six waypoints.

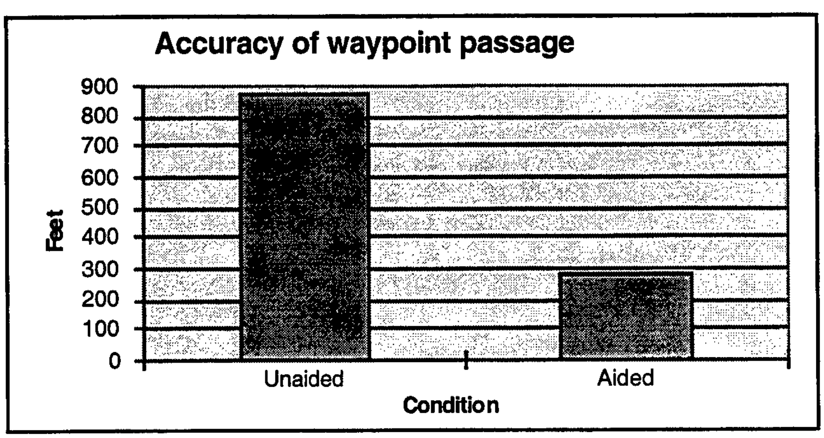


Figure 6-7. Waypoint passage results.

Landing distances from the HA. The distances between the designated position of the HA and the actual landing positions of the aircraft differed significantly, t(12) = 4.679, p<.001; the mean distance in the unaided condition was 1,130 feet (SD = 588) and the mean distance in the aided condition was 262 feet (SD = 481). All of the pilots but one were closer to the HA with the earth-fixed waypoint markers. Had that pilot's score not been included in the group, the mean distance from the HA for the aided condition would have been halved (131 feet).

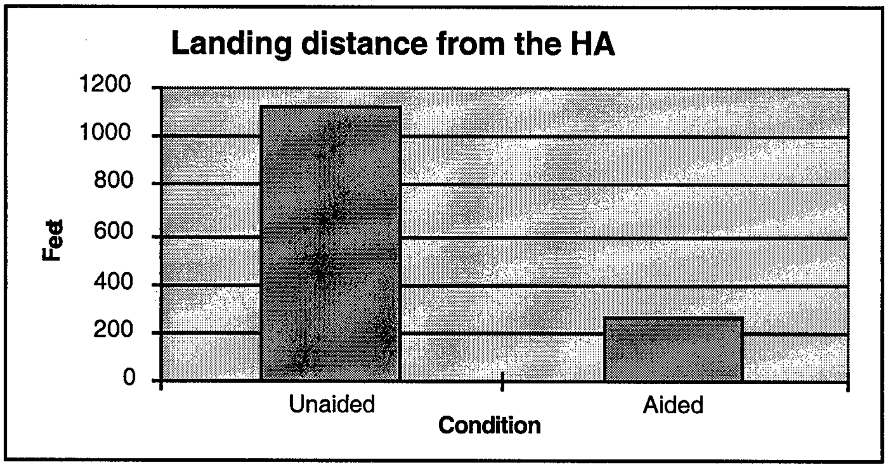


Figure 6-8. HA landing distance results.

Landing distances from the BP. The distances between the designated position of the BP and the actual landing positions of the aircraft differed significantly, t(11) = 5.458, p<.001, in a manner very similar to that observed with the HA landing distances. The mean distance in the unaided condition was 1,111 feet (SD = 529) and the mean distance in the aided condition was 256 feet (SD = 406). All of the pilots landed closer to the BP with the waypoint markers than without them. Again, however, one of the pilots made a large landing error (1500 feet) even with the waypoint marker. Had his score not been included in the group, the mean distance from the HA for the aided condition would have been much smaller (143 feet).

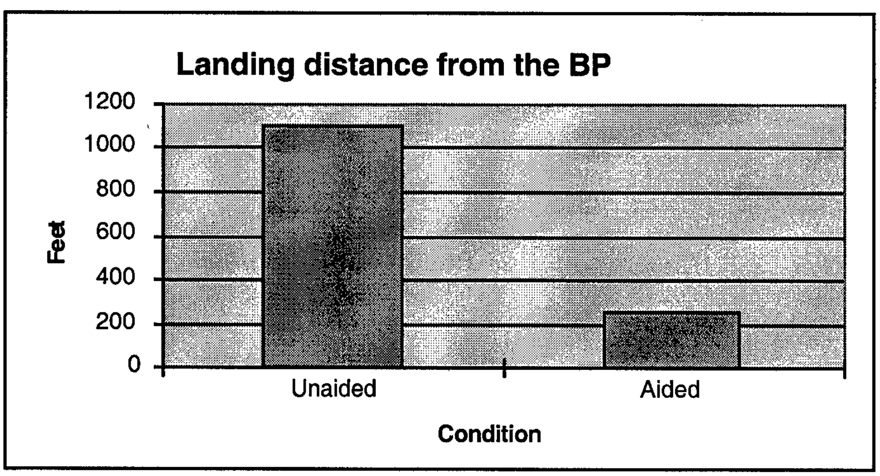


Figure 6-9. BP landing distance results.

Mean exposure time to the EA enroute. In both unaided and aided conditions, pilots were advised to maintain masking behind landforms to prevent their detection by enemy forces in the EA. The unaided group accumulated an average of 28.7 seconds of exposure time (SD = 27.0), and the aided group accumulated an average of only 15.8 seconds (SD = 22.2). This difference was significant; $t(13) = 2.234$, $p<.05$.

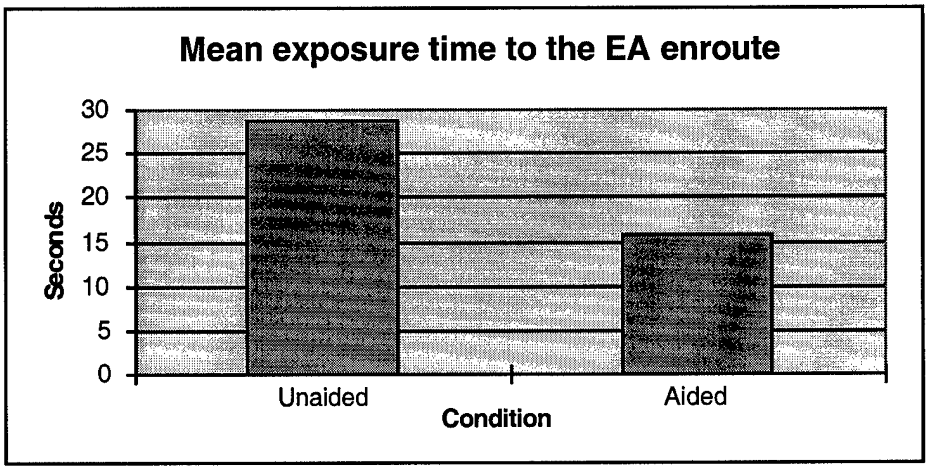


Figure 6-10. Exposure time results.

Mean number of exposure events. The unaided group exposure events ranged from zero (one pilot) to four with a mean of 1.93 events (SD = .997). The aided group exposure events ranged from zero (six pilots) to three with a mean of 1.21 events (SD = 1.188). This difference was also significant; $t(13) = 2.687$, $p<.025$.

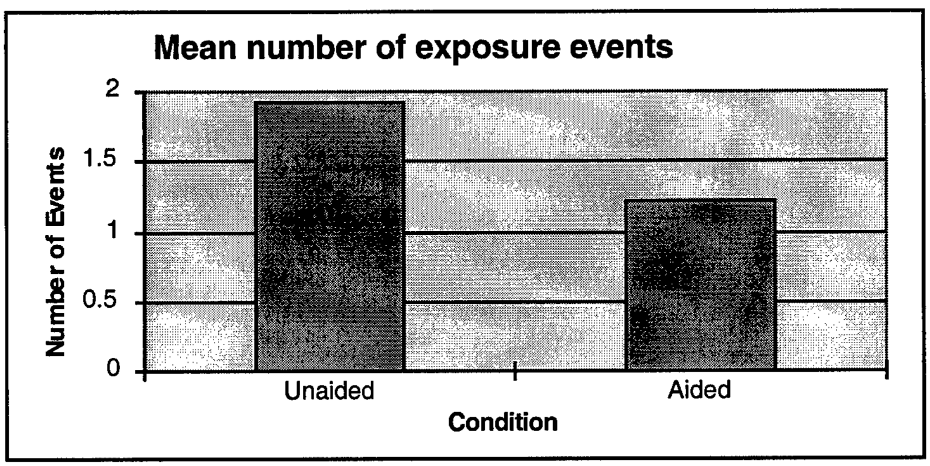


Figure 6-11. Exposure event results.

Total exposure time during the bob-up. The exposure time during the bob-up maneuver was collected primarily to indicate whether or not the pilots were able to comply with the experiment instructions to complete the maneuver rapidly. The exposure time prior to firing the second shot was 22.7 seconds (SD = 12.3) for the unaided condition and 20.5 seconds (SD = 13.0) for the aided condition. The exposure times from first exposure to remasking after the bob-down were 42.3 seconds

(SD =19.7) for the unaided condition and 39 seconds (SD =18.6) for the aided condition. Neither of these differences were statistically significant.

Accuracy of altitude maintenance. The mean RMSE around the 100 foot AGL altitude was 112 feet (SD =48.1) for the unaided condition and 93 feet (SD = 42.7) for the aided condition. This difference was not statistically significant.

Accuracy of airspeed maintenance. The mean RMSE about the 60-knot airspeed was 16 knots (SD = 7.1) for the unaided condition and 22 knots (SD =6.5) for the aided condition. This difference was not statistically significant.

Number of targets of opportunity detected. The average number of targets of opportunity hit, out of a possible 4 was 1.6 for the unaided condition (SD = .73) and 1.7 for the aided condition (SD = 1.43). This difference was not statistically significant.

Accuracy of sector identification in the EA. The utility of the earth-fixed EA symbology was particularly dramatic. The average error (as a sum of the two shots) was 1666 feet (SD = 869) in the unaided condition and 14 feet (SD = 54) in the aided condition. Not surprisingly this difference was statistically significant $t(13) = 7.147$, $p<.001$. In the unaided condition, only 3 of 28 shots were directed at the correct points. In the aided condition, 27 of 28 shots were fired at the tanks on the sector boundaries; there was only one stray shot that was directed at a tank 201 feet away from the correct one.

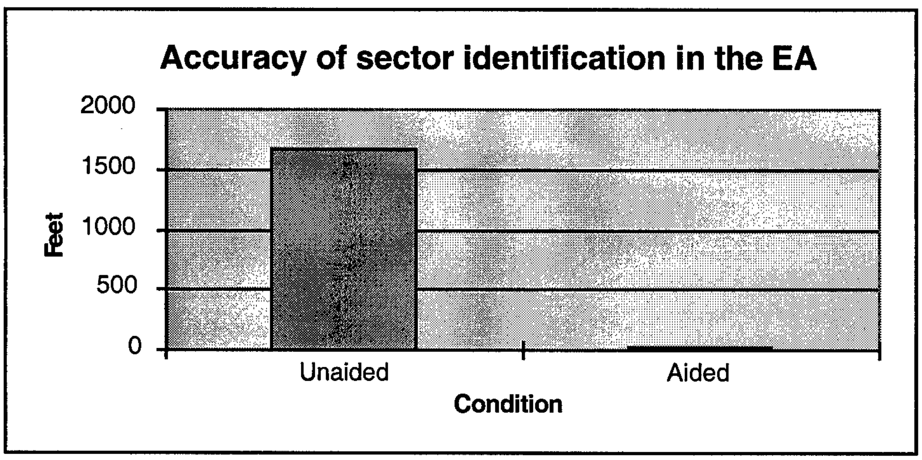


Figure 6-12. Firing sector identification results.

It should be emphasized that the errors in the unaided condition resulted both from inaccurately selecting the battle position, as well as inaccuracies in map interpretation and terrain analysis in identifying the sector boundaries. In the aided condition, the landing distances were several hundred feet closer to the BP, on the average, than in the unaided condition. Nevertheless, BP errors do not explain the great differences in performance between the aided and unaided conditions. The comparison of the shot accuracy and the BP accuracy for the unaided and aided conditions is facilitated by Figures 6-13 and 6-14.

Unaided condition. The shots taken by the 14 Apache pilots in attempting to identify the tanks on the boundaries of the center fire sector. The + signs show the position from which the shots were fired (the pilots identification of the BP position). The asterisks indicate four cases in which BP selection error was exceedingly large and the aircraft was artificially returned to the correct BP by the experimenter.

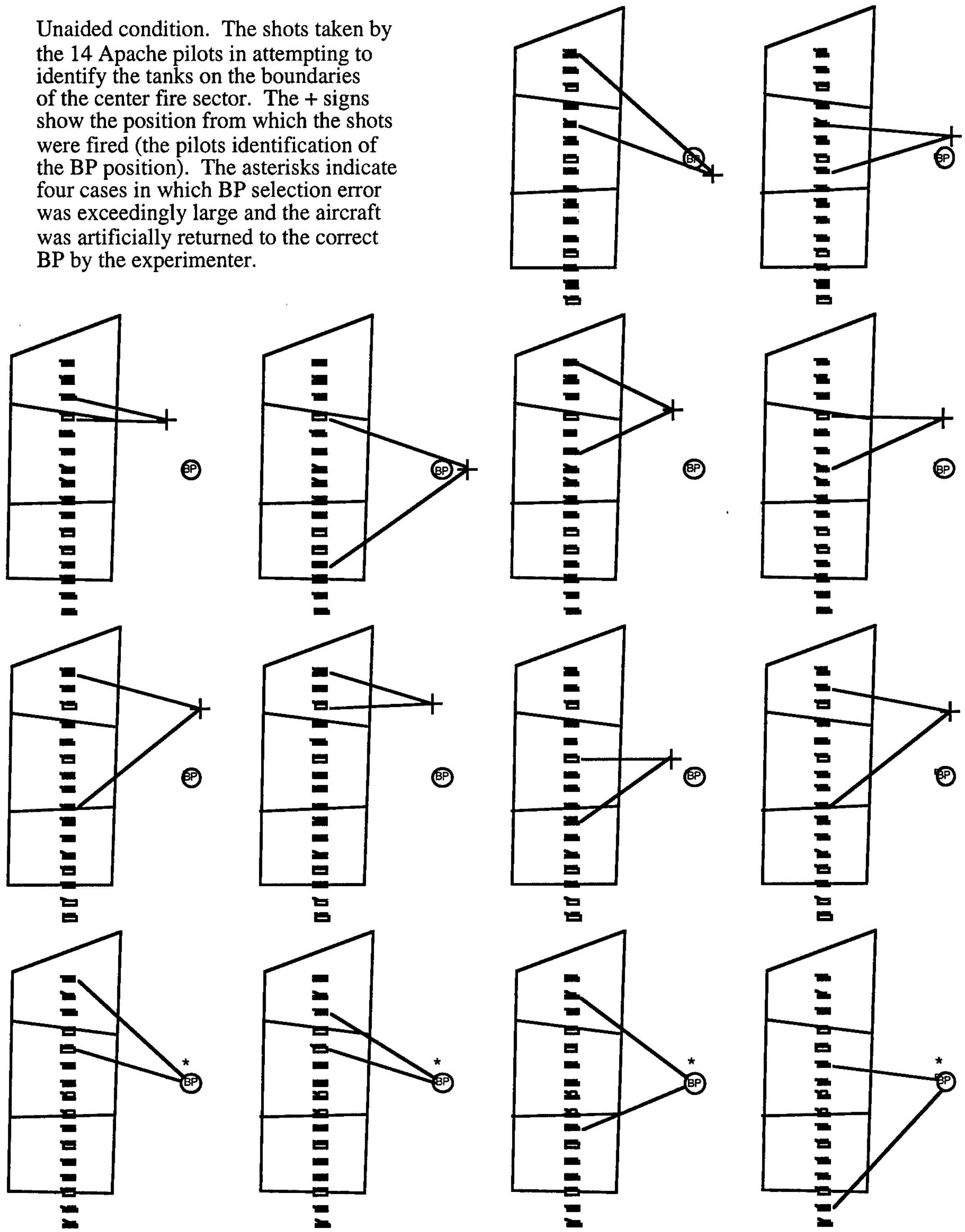


Figure 6-13. Shots fired in the EA in the unaided condition.

Aided condition. The shots taken by the14 Apache pilots in attempting to identify the tanks on the boundaries of the center fire sector. The + signs show the position from which the shots were fired (the pilots identification of the BP position). The asterisk indicates one case in which BP selection error was exceedingly large and the aircraft was artificially returned to the correct BP by the experimenter. The # indicates one case in which the firing position could not be exactly identified. The E shows the single error.

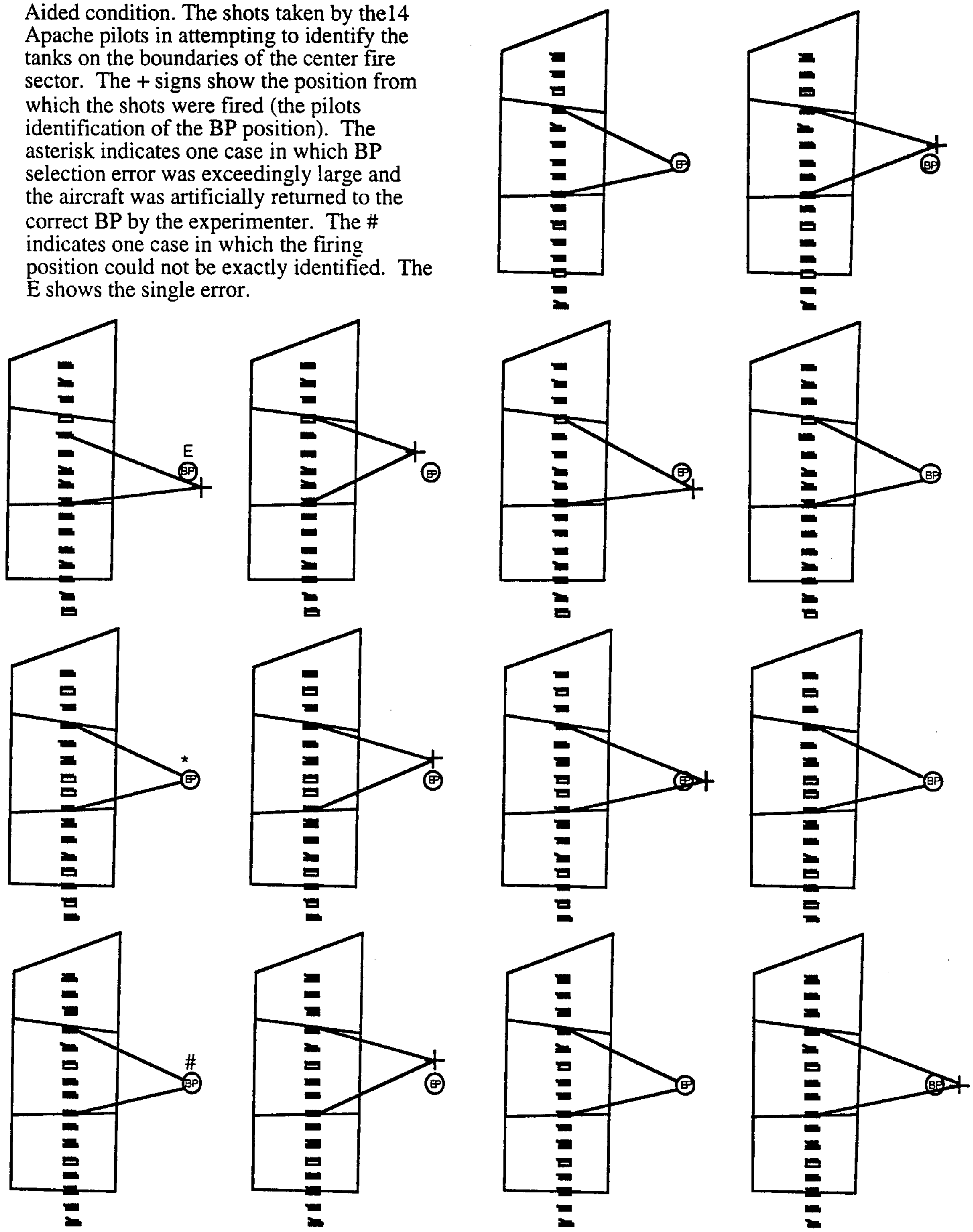


Figure 6-14. Shots fired in the EA in the aided condition.

Figure 6-13 shows that no pilot in the unaided group was able to successfully identify the assigned fire sector. Regardless of the firing position, the extent of the assigned firing sector shown on the map was vastly over- and under-estimated when viewing the terrain. Although their BP selection errors were often large, elimination of these errors did not result in correct firing sector identification, as demonstrated by the scores of the four pilots shown at the bottom of Figure 6-13.

During conduct of the unaided condition, these four pilots missed the command heading cue shift and overflew the BP by large distances. In these cases, the experimenter stopped the aircraft, scored a 1500 foot error, and returned the aircraft to the BP. As shown at the bottom of Figure 6-13, however, these pilots were, like the other ten pilots, unable to accurately identify the tanks marking the fire sector boundaries. As further evidence that the BP selection error did not account for the EA shot errors, four other pilots in the unaided group landed fairly closed to the BP but were unable to accurately identify the firing sector.

In contrast, Figure 6-14, in the aided condition, shows that nearly all (27 of 28) of the shots were correct, even though the pilots had misidentified the BP position by an average of 226 feet. The reason for the single shot error is unclear. It may have been that the correct target was momentarily obscured behind the canopy rail or simply that a transitory head alignment error shifted the reticle toward the adjacent tank.

Workload reduction estimates. Although there many techniques have been used to estimate workload and workload reduction, most of these require a substantial investment of time. In attempting to gather as much flight and knowledge data as possible in the 90 minutes available with each pilot, we chose a very simple metric for workload reduction estimates. We simply asked the pilots, given the flights with and without the ground-fixed symbols in PRISMS, how much their workload would be reduced for similar operations in the aircraft. The responses were extraordinarily favorable for these symbols. The mean workload reduction attributable to the waypoint symbols was estimated at 55% (SD = 25.4) The mean workload reduction attributable to the EA symbols was estimated at 69% (SD = 24.3). These are certainly attention-getting votes of confidence for these new symbol types. Additional interview information supplementing these figures is described later in this report.

Head angle measurements. One of the objectives of providing pilots with earth-fixed symbols is to increase situation awareness. Earth-fixed symbols could do this through indicating the positions of important elements in the head up view and also through reducing workload such that the pilot would have more time available to turn his head and scan the terrain surrounding him. In order to determine whether such an effect was immediately observable, timers were used to measure the time in seconds that the head angle fell within each of nine 20-degree sectors in the frontal 180° field of regard, as shown in Figure 6-15. The head angle metrics were summed across the first four flight legs, the legs between Waypoint 1 and the HA, in which the pilots had been instructed to search for targets of opportunity. The field of view of the helmet was 60° x 47°, so the pilot's eye movements would allow him to view up to an additional 30 degrees to the side beyond the head

angle indicated by the timer. In the unaided condition, pilots head angles were limited to the center sector during 51% of the time (SD = 15.5). Surprisingly, in the aided condition, pilots head angles were limited to the center sector during 67% of the time (SD = 12.3). This difference is statistically significant; $t(13) = 4.99$, $p<.001$). The distribution of times across the nine sectors is shown in Figure 6-16.

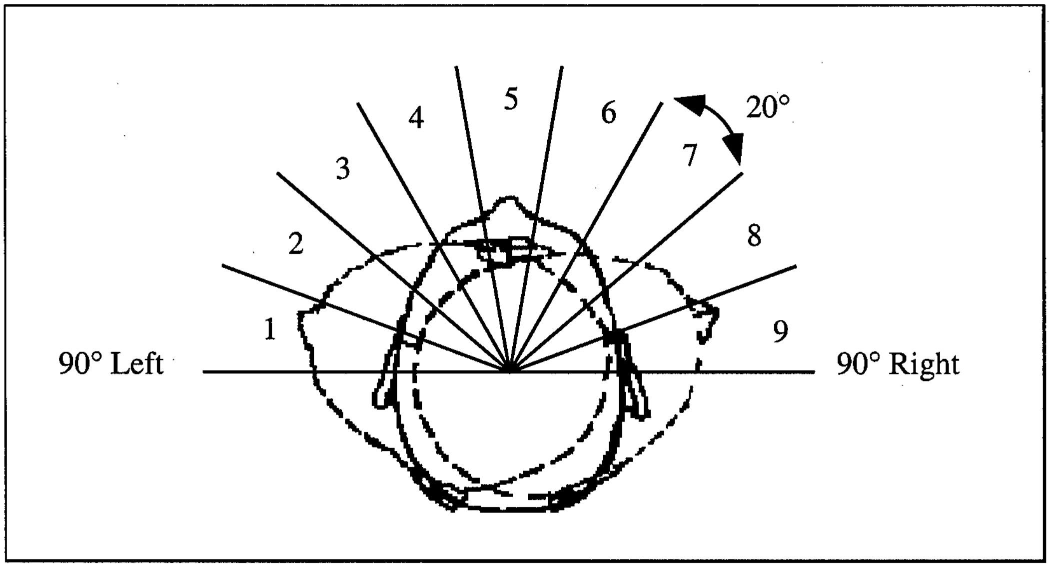


Figure 6-15. The nine 20-degree sectors used in the experiment.

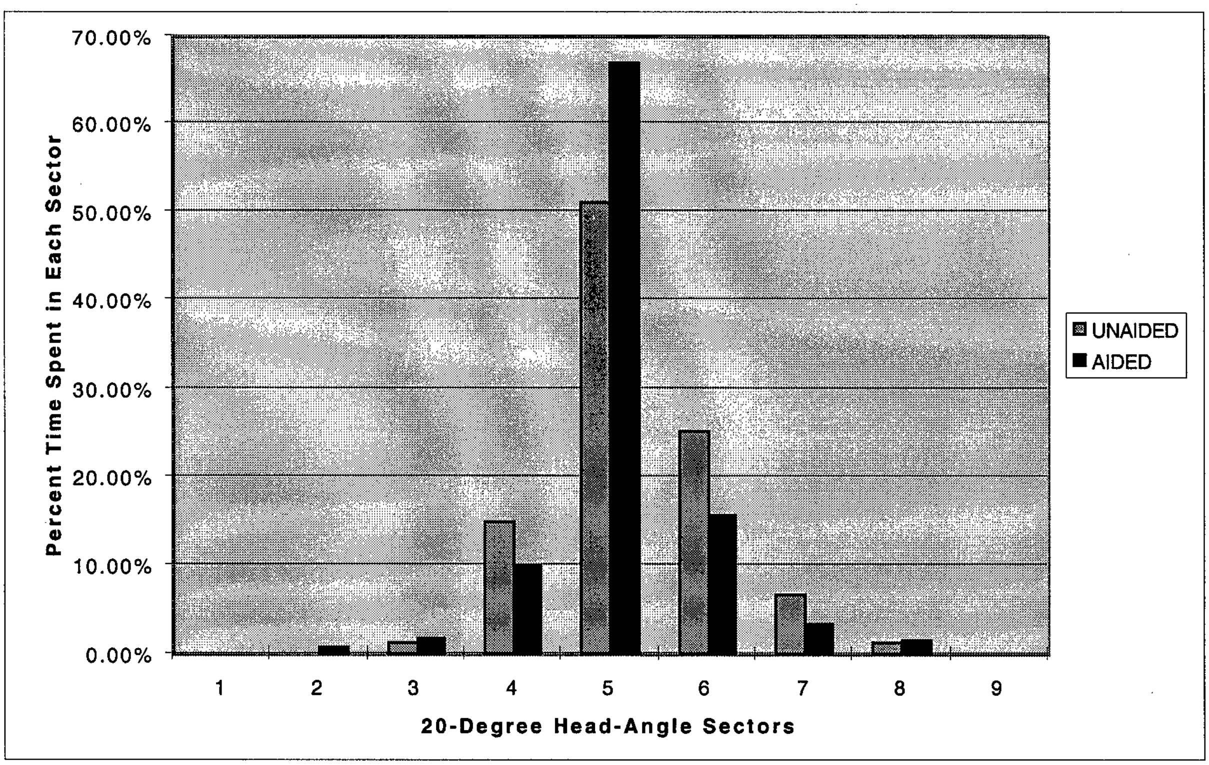


Figure 6-16. Percent of time in nine 20° head angle sectors.

Number of inadvertent ground contacts. The measurement of the number of inadvertent ground contacts was added almost as an afterthought. This was a fortunate inclusion because it revealed some dramatic differences between the aided and unaided conditions, Only three of the pilots in the unaided condition struck the ground during the mission, and none struck the ground more than once (Mean = 0.21, SD = 0.43). In marked contrast, in the aided condition every single pilot struck the ground at least once, and seven of them struck the ground more than once (Mean =1.71, SD = 1.07) for a total of 24 ground strikes. This difference is statistically significant: $t(13) = -4.364$ $p<.001$, and is also of great practical significance. How is it that the waypoint symbols, despite their demonstrated superiority in waypoint passing distance, HA and BP landing distances, and estimated workload reduction, can lead to eight times as many inadvertent ground contacts? This question will be addressed in the Discussion section.

Discussion of Experiment Results

Repeated Measures Design

There are two basic methods for designing an experiment such as this one. First, it would be possible to allocate test subjects (pilots) to one of two groups: the unaided group and the aided group, perhaps attempting to somehow match the groups for experience, skill, or aptitude. Because of the very large range of individual differences in pilot capabilities, a fairly large number of pilots would be needed in each group; perhaps 12 per group, at a minimum. Unfortunately, it is nearly impossible to obtain access to a group of 24 or more Apache pilots, simply because of the existing demands on their time.

The second method for designing an experiment to compare two conditions is the "repeated measures" approach, letting each individual serve as his or her own control group by participating in both conditions. Typically, to control for practice effects or other potential effects of performing the tasks in a certain order, half of the subjects perform the two conditions in one order and the other half perform them in the opposite order.

This dual-order approach was impossible in the present experiment because the aided condition could not be shown before the unaided condition. That is, the waypoints and EA markers showed the correct positions so that the pilots would still remember where they were (approximately) when they performed the unaided condition. Thus, all of the pilots in our experiment flew the unaided condition followed by the aided condition and it is not impossible that there was some learning during the first flight that might have aided in the performance of the second. However, during the first flight, the experimenters were careful not to provide any feedback to the pilot regarding the accuracy of their waypoint crossings, landings, shots at the sector boundaries in the EA, or on any other performance metric. So, any learning that took place would not have directly influenced the scores on these performance measures.

As a check on potential learning effects, we considered having a few pilots fly the unaided condition twice, to determine whether the metric scores improved on the second unaided flight. However, after having observed the very large inter-subject and intra-subject performance variability, we decided that little would be gained from such a method unless many pilots were included. Unfortunately, such an approach would have reduced the number of pilots available to fly in the experiment itself. In any case, from the dramatic differences in performance and from the high praise for the symbols from the pilots, it seems clear that the experimental results are almost entirely based on the presence or absence of the earth-fixed symbols and not on practice effects.

Accuracy of Position Finding

Three metrics were used to determine the pilot's ability to arrive at designated points with and without the new earth-fixed waypoint markers: accuracy of waypoint passage, landing distance from the HA, and landing distance from the BP. The pilots' performance on these metrics showed that with the virtual markers, errors were only 33%, 23%, and 23% as great, respectively, as those observed without these earth-fixed markers.

The magnitude of these improvements was somewhat surprising since the command heading caret alone could be used (and was in some instances) to accurately reach the waypoint. In order to do so, however, the caret had to be kept centered continuously. If error distance was allowed to begin increasing rather than decreasing when the aircraft was already close to the waypoint (within 500 feet), the system would automatically switch the command heading symbol to the next waypoint in the logical assumption that the waypoint had been passed. Because the pilot did not know the exact distance to the waypoints, it was thus imperative to keep the caret centered. Not only is keeping the caret centered a more demanding task than simply flying toward a waypoint symbol visible in the terrain, but enforced straight-line flight does not permit the pilot to take advantage of terrain for cover and concealment by following low areas that are off the most direct path to the next waypoint.

Although some pilots are quite adept at map interpretation and terrain analysis, permitting reasonably accurate estimates of current aircraft position, many have become accustomed to depending upon the CPG to use the Doppler and the paper map to periodically determine present position and distance to the next waypoint and to verbally relay them to the pilot.

In the unaided condition, the pilot was tasked with estimating waypoint distance (based on dead reckoning and map-terrain correlation) and slowing appropriately for landings. When the command heading caret moved rapidly to a new direction, the pilot knew that the waypoint, HA, or BP had been reached, but if the aircraft were still traveling at 60 knots, it would be certain to overfly the position before landing. In contrast, the waypoint virtual markers permitted the pilots to slow prior to landing, and furthermore, to have a clear indication of the specific position designated for the landing.

Exposure Metrics

Two metrics were employed to determine the pilot's ability to traverse the terrain between the HA and the BP without intervisibility between the aircraft and the enemy armor unit to the west: total exposure time to the EA and total number of exposure events. The condition aided by the virtual EA markers produced only 55% as much exposure time, and 63% as many exposure events.

The pilots were instructed to fly at about 40 knots, but no flight altitude was suggested other than that they were to "maintain masking" from the enemy positions. In fact, an altitude of approximately 50 feet was the upper limit for maintaining masking. The ridgeline between the enemy tanks and the path to the BP was of sufficient altitude to provide continuous masking.

It is likely that the superior results for the aided condition result from the cues provided by the dotted red lines of the EA symbol. The EA lines are depicted as dots when the EA is obscured by the masking terrain. Thus, if the dotted red lines moved near the top of the masking terrain it would be evident that masking was about to be lost. And, if the dotted lines became solid, this event would provided an unmistakable warning of exposure to the enemy forces. Although enemy tanks could be seen by the pilot during moments of exposure, they would have been a much less salient cue than the bright solid red lines of the EA.

Secondary Task Metrics

Three additional metrics were employed to attempt to observe indirect benefits of the virtual waypoint markers: maintaining designated altitude and airspeed, and searching for targets of opportunity. We had expected that the virtual waypoint markers would greatly reduce workload, as indeed the subjective reports dramatically proved. It was surmised that reduced workload in the navigation task might be reflected in the secondary tasks, but the performances of these tasks, did not significantly differ between the aided and unaided conditions.

Although it seemed probable that reduction of overall workload resulting from use of the earth-fixed symbology might be reflected in the pilots' ability to devote more cognitive resources to these secondary tasks, there is no evidence that this was the case. The lack of a significant difference in the altitude and airspeed metrics does not indicate that workload was not reduced by the new symbols; only that any newly available resources were not allocated to these particular tasks. Such resources might have been devoted to other flight and tactical tasks, such as maintaining aircraft attitude or map-terrain correlation activities.

For the target search task, like the altitude and airspeed maintenance tasks, it seemed reasonable that a reduction in overall workload from use of the ground-fixed waypoint markers might be reflected in more time available to the pilots for turning their heads to search the terrain for targets. Because most of the targets were placed well off the flight path and behind landforms, rather large (but not uncomfortable) head movements were required for their detection. In general, however, it was revealed that the pilots spent most of the time with their heads addressing the

center 20° sector of their potential field of regard, regardless of the presence or absence of waypoint marker symbols.

Head Scanning and Ground Contacts

Despite the pilots' overwhelming preference for the virtual waypoint symbols and the very large performance enhancements attributable to them, two of the outcomes of their presence were disturbing. First, the reduced head scanning behavior and second, the increased frequency of inadvertent ground contacts observed in the aided condition seem to indicate that the new symbology was unduly distracting the pilots from their normal head movement scanning and their HMD symbology scanning. The head angle measurements showed that the pilots in the aided condition spent 31% more time looking roughly straight ahead than when they were in the unaided condition. The ground contact data showed that pilots in the aided condition were, startlingly, 8 times as likely to inadvertently contact the ground as when they were in the unaided condition.

Such findings are reminiscent of the series of studies on "attentional tunneling" and "cognitive capture" performed over the past 15 years (e.g., Weintraub, Haines & Randle, 1984; Larish & Wickins, 1991; Foyle, Sanford, & McCann, 1991). Indeed, some of the pilots reported a kind of "fixation" with the waypoint markers. We have previously analyzed and summarized this line of research (Rogers, & Spiker, 1995) and would find it surprising that a symbol that is as uncomplicated, conformal, out-the-window-oriented, and holistically processed as the waypoint marker could lead to attentional tunneling. In short, it should be little more likely to induce attentional tunneling than a recognizable tree at the waypoint.

It seemed particularly odd that the experimenters and several experienced helicopter pilots had flown with this symbology in our laboratory many times without experiencing cognitive capture effects, yet every one of the pilots in the experiment seemed to have had this experience. This led us to closely re-examine the nature of the symbol we had created. There are, of course, many variables to consider in constructing such a symbol and controlling its behavior. Because we did not have the specifications for the Comanche symbol, we simply constructed our own. It now appears that one of our design decisions may have created an illusion that confused the pilots in the experiment especially since the experiment instructions did not include certain details regarding the symbol's behavior.

Specifically, although the waypoint symbol circle grew as the aircraft approached the waypoint, the perspective could not be perfectly accurate. For example, in order to see a distant waypoint symbol on the HMD, it's size cannot be allowed to diminish too much. Also, it's size cannot increase too much as it is approached or the circle will become too large to be seen in the field of view and the staff will block the pilot's view of the terrain. Thus, we set distances from the aircraft at which the minimum and maximum circle sizes would be reached.

This dynamic scaling method presented the symbol at a single minimum size when 5,000 feet or more away and increased it proportionally to distance until it was

1000 feet away (with no further size changes at lesser distances). At 1000 feet or less, the symbol appeared to be about 105 feet tall, and pilots may have assumed that it was similar to a "highway in the sky" and attempted to fly under or through the circle, which was not possible. The symbol plane was always kept perpendicular to the viewer, so that it would not change in shape with changes in the aircraft's position. One of the results of this approach, however, is that the symbol would appear to "lay down" on the ground as it was overflown. Thus, attempting to fly though the circle would lead directly to a ground impact.

The experimenters and other pilots who had previously flown the system were aware of the symbol behavior and thus were not drawn into the ground. It is probable that the ground impacts observed in the experiment would have been eliminated had we has simply told the subjects to "maintain your altitude and don't try to fly through the hoop."

Subsequent to the completion of the experiment we have tested a "pitch enable" behavior for the waypoint marker, which causes the symbol to realistically compress as it is overflown, the staff becoming shorter and the circle becoming increasingly oval and then disappearing. This feature alone seems to reduce much of the perceptual problem. We later learned that the Comanche virtual waypoint marker circle is always maintained just above the horizon, partially to deter such problems (B.E. Hamilton, personal communication, September 23, 1998). Of course there are many ways to provide this type of information and PRISMS flexibility facilitates the testing of these different approaches. For example, the circle could be placed at a fixed altitude above ground level and the staff extended to reach the way-point on the ground, so that a concept similar to the highway-in-the-sky could be evaluated.

There remains the issue of the greater period of time looking forward than rotating the head to scan the environment when the waypoint symbol was present. However, several pilot's commented that the fixation on the symbols was experienced only because they were new and novel and that it would take only a little time to become accustomed to them. One pilot said that proper use would come with experience and estimated that "another hour of practice" would be sufficient.

Virtual EA Marker Symbology

The extraordinary success of the EA symbology in both objective and subjective measures has very important operational implications. The EA is typically defined by lines drawn on a paper map or transparent overlay and is often subdivided into fire sectors assigned to different friendly units. As described in Field Manual 1-112; Attack Helicopter Operations, EAs are used because it is critically important to correctly distribute and control the fires from available weapons. Attack helicopters must fire only in their assigned sectors in order to prevent fratricide, to avoid target overkill (such as firing 10 missiles at one tank) to avoid target underkill, and to use each weapon system in its best role.

Effective use of EAs depends largely upon the presence of some easily recognizable features in the terrain. Unfortunately, the battlefield area does not always offer obvious, discernible landforms and other terrain features so that finding the EA and the correct sector at night in unfamiliar terrain is an extremely difficult task. Near the battle area, the CPG's primary responsibility is operating the aircraft's complex weapon systems, and he has little time to aid the pilot in navigation tasks.

The pilot must frequently move between battle positions and firing positions in order to deceive the enemy, yet orient the aircraft properly for the CPG's use of the weapons in the correct firing sector, an area that may be very difficult to identify. The problem is made even more difficult if the planned mission has been changed enroute, due to unforeseen changes in the situation, so that new EA positions and sectors must be assigned by radio. By comparison to actual operational conditions, the unaided experimental task was relatively easy. As demonstrated by the PRISMS experiment, however, the unmistakable definition of fire sectors by HMD symbology provides dramatic performance advantages.

Summary

The experiment was most effective in demonstrating the overwhelming advantages of the new earth-fixed symbol types for use with HMDs in military helicopters. The accuracy of position-finding in the terrain improved by approximately 300 to 400 percent with display of the virtual waypoint symbols. The exposure to enemy forces through inadvertent unmasking was reduced by approximately one half. The EA fire sector identification accuracy was improved by about 12,000 percent.

In addition to these important findings, the experiment has also demonstrated the relative ease with which PRISMS can be used to construct and edit experimental sessions, add and improve symbology features and behaviors, provide realistic terrain and objects, and provide an extensive range of performance measures -- all in a package that is transportable to the field. PRISMS has not only fulfilled its project objectives, but will continue to provide researchers with a powerful but inexpensive tool for many years to come.

Section 7: Symbology Evaluations with PRISMS; Demonstrations, Interviews, and Survey

Introduction

This section provides a summation of pilot subjective data, amplifying the objective data gathered during the experiment described in the previous section. The first two subsections present the pilots' responses to the waypoint marker symbology and the EA marker symbology. Because there were many more opportunities for new HMD symbols than could be evaluated in formal experiments in the scope of this project and because PRISMS has been designed for "quick-look" evaluations and knowledge acquisition sessions, we elected to construct demonstration sessions to show the pilots some of these new concepts.

The five new concepts demonstrated included special new symbology for presenting slope landing data, wind speed and direction, required speed for accurate arrival time, ASE threat direction, and flight path prediction. Each of the demonstration sessions are described in terms of the background and reasons for their development, the instructions given to the pilots before the demonstration, the pilots' overall subjective responses, specific topics pertinent to each symbol, and the pilots' suggestions for intelligent symbology moding opportunities.

Although the experiment and the five demonstrations permitted the gathering of a great deal of valuable data, there was not sufficient time for even cursory evaluations of the scores of potential symbols identified during the project. In order to prioritize future research directions with PRISMS, we conducted a survey to determine the relative importance of new HMD symbol types. This final section of the report concludes with the results of this survey.

Waypoint Marker Symbology - Summary of Pilots' Comments

Following a planned route at low nap-of-the-earth (NOE) flight altitudes is an extremely demanding task. Other than a rough sketch map on his kneeboard and the command heading caret in the heading scale, the Apache pilot is almost entirely dependent on the copilot-gunner (CPG) for navigation information. As a result, the pilot's situation awareness is often less than optimal. It is usually too dangerous to look down at the sketch map when flying NOE, especially at night. In some cases the pilot may try to memorize the flight legs (the heading and distance to each new waypoint). The CPG currently must help the pilot by "talking him through" the waypoints with the use of a map and avionics in the front cockpit.

Because of these known operational difficulties and given our search for high-payoff improvements, the first new symbol to be chosen for experimental evaluation was the virtual waypoint marker, similar in some respects to one of the advanced features planned for the RAH-66 Comanche helicopter. It is an earth-fixed symbol that appears to the pilot to be a giant map-tack or "lollipop" stuck in the real-world terrain to show upcoming waypoints, thus reducing navigational workload.

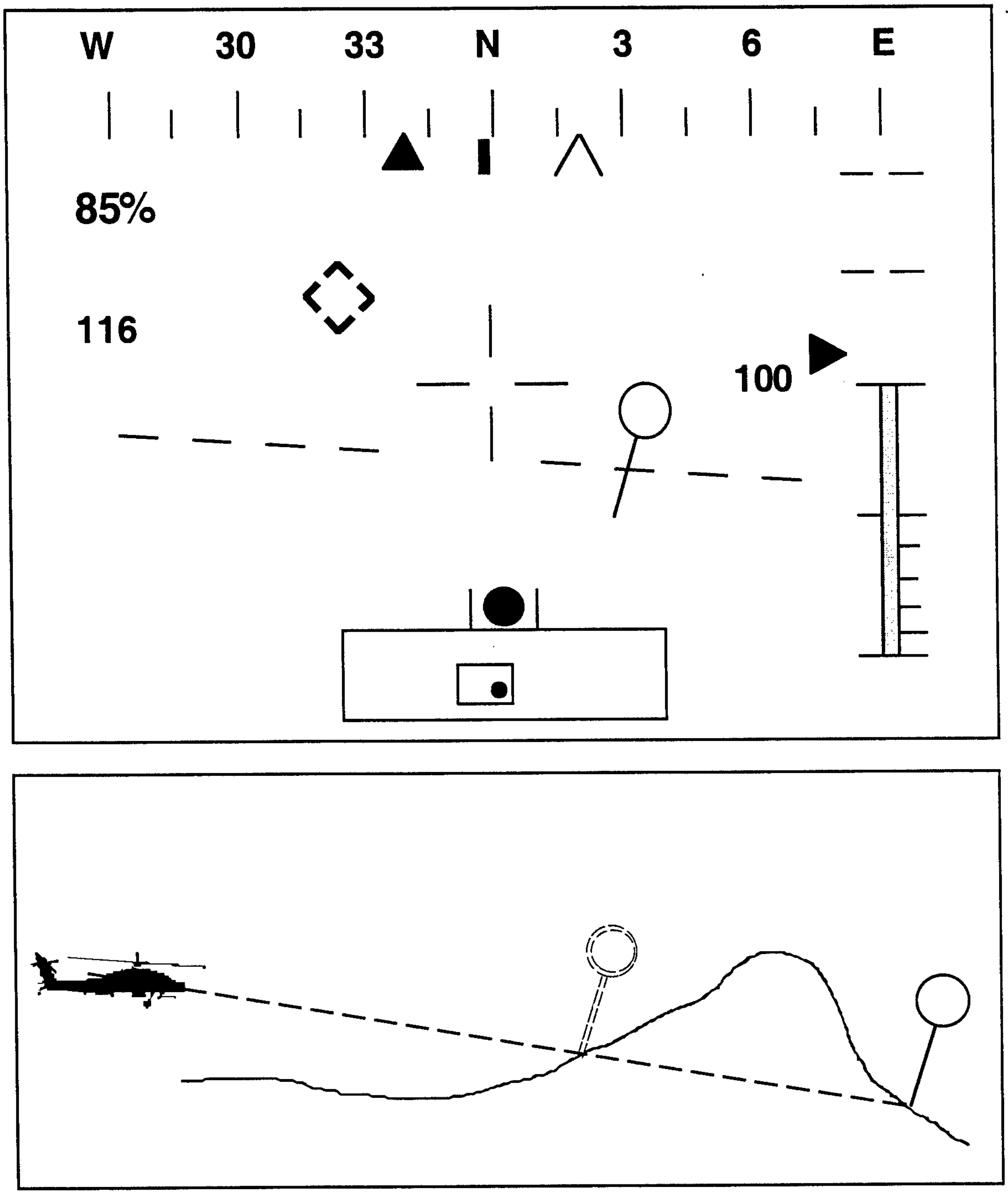


Figure 7-1. The appearance of the virtual waypoint marker with the other HMD symbology (above) and an explanation of the meaning of the dashed symbol (below) showing a waypoint obscured by intervening terrain.

Instructions to Pilots (Aided Condition)

The pilots were instructed to examine a 1:24,000-scale paper map with a flight plan overlay. "The mission will begin just northeast of Waypoint 1 and continue through Waypoints 2, 3, and 4 to a Holding Area, then on to a Battle Position. Along

the route to the Holding Area, try to maintain 60 knots and 100 ft AGL altitude. You need not follow straight flight legs between waypoints, but you must overfly the waypoints. In addition to the Command Heading Caret under the magnetic heading scale at the top of the display, we will add some symbols that point out the waypoints to you. They look like "lollipops" [The SME was shown a drawing of the virtual waypoint symbol]. When you cross a waypoint, the symbol will appear over the next waypoint. If the next waypoint is obscured by terrain between it and your position, the symbol is shown by a red, dashed outline."

In addition, another figure was shown to the pilots to depict an additional cue to waypoint and landing positions. The cue had the appearance of a small "igloo" 10 feet in diameter. This symbol, unlike the waypoint symbol, did not disappear (jump to the next waypoint) as the aircraft passed the waypoint position. Thus, it could be used as a continuing reference point which was particularly useful for landings.

Overall Response

Without exception, the pilots praised the virtual waypoint marker utility. Comments included "lots of merit," "definitely a workload reduction," "I love it," "excellent," "very useful," "boy, I like that," "Nice," "definitely going to help you," and "very valuable." They noted that the markers were much better than following the heading cursor because it was unnecessary to fly a straight line between waypoints. With the waypoint markers, the pilot could follow a frequently changing course offering the best cover and concealment between waypoints.

During planning, the pilots attempt to select easily identifiable features like road intersections or mountain peaks as good check features, but such features are not always available, or may be difficult to see in the actual terrain. As another pilot put it, the "where am I?" kinds of questions "happen constantly." and the waypoint markers would "really help situation awareness."

They observed that in some cases the pilot doesn't always "have tons of work to do if the guy in front is navigating," but if the CPG gets "task-overloaded" or makes some mistakes, "things become much tougher." The front-seater is particularly busy working on navigation, continuously figuring the heading and distance to waypoints, using a strip map and the Doppler system. He is head-down most of the time, and verbally relays course and speed information to the pilot, attempting to bring the aircraft to the waypoints accurately and on time.

Under this pressure he sometimes makes Doppler input mistakes and "the pilot must always anticipate where his directions should take you" and tell the CPG when he must be wrong. The navigation task is "especially tough if you are the lead aircraft -- knowing where the next waypoint is, is much more significant with people following you."

The waypoint markers would definitely reduce workload for both men, letting them concentrate on other tasks. They would let the CPG "hunt for targets" and let the pilot make better use the terrain and look for targets of opportunity.

Additional Information Recommended

Nearly all of the pilots believed that the waypoint marker information should be augmented to include waypoint distance from the aircraft, in kilometers. As one pilot explained, "The waypoint symbol gives an intuitive sense of direction, but not distance. I want the range so I can use the terrain to advantage." The range of the waypoint is currently obtained from the Doppler by the CPG and passed to the pilot. The range data can become especially important when trying to make accurate passage times, "such as FLOT passage times."

Several pilots suggested that the waypoint should be specifically identified by number. Some sort of coding should permit easily matching a waypoint on the map to the waypoint symbol seen in the HMD. The pilots cautioned that the Doppler numbers are not the same as the waypoint numbers. For example, Doppler Number 5 could be Waypoint Number 17, which tends to be confusing. One pilot said he uses the taxonomy of "waypoint" to be equivalent of Doppler number, and "air control point" (ACP) to be the number on the mission plan and another term such as FARP to describe the nature of the position. In any case, the waypoint number on the mission plan is the one that should be shown with the symbol.

Some of the pilots also thought that letters, shape codes, or color codes should be used to identify the earth fixed symbols. "You could use T for a target, H for holding area, F for FARP, A for ACP," and so forth. This could save a lot of time since the pilot is "always asking the front seater what's where." Another code might be used when using the laser to "store points for targets that the aircraft could attack on the egress route." Using conformal markers this way could permit designation of many more targets for the second pass through the same route.

The pilots were divided on where to show the distance and waypoint identifier. Most believed that it should be inside the waypoint marker circle, or adjacent to it, but others were concerned about its readability if small enough or the clutter it would introduce if large enough. Two of the pilots mentioned that their unit was about to receive the Embedded GPS Integration (EGI) retrofit. When a waypoint is selected, this unit will display the range to the waypoint in the right side of the High Action Display (HAD). The EGI display may thus provide the necessary distance information without additional clutter to the center of the waypoint symbol.

Moding Control Suggestions

With regard to symbol moding, the automatic change to show the next waypoint as each waypoint is passed was met with approval. All of the pilots stated that they wanted at least one (the next) waypoint symbol displayed at all times. Some said that they would like to be able to call up any other waypoint to determine its relative location and distance. Most felt that a single waypoint was enough, although a second might be useful to indicate the direction of the next turn. One pilot suggested that if the WAS switch was used to select Hellfire or rockets, the waypoint symbols could be removed to reduce clutter and the command heading caret used instead.

Engagement Area Symbology - Summary of Pilots' Comments

Background

This new symbol belongs to a class of more complex, earth-fixed markers ("augmented reality") proposed after our interviews with expert Apache pilots during the Phase I effort This class of symbols would aid the pilot by pointing out critical tactical demarcations and zones on the ground such as phase lines, planned artillery fires, international or unit boundaries, holding areas, battle positions, and target engagement areas. Such markers are presently defined on transparent operations overlays superimposed on paper topographic maps that are very difficult to use in the cockpit. If they were instead presented with HMD symbology in an earth-fixed frame of reference so as to appear "painted" on the ground, the benefits could include reduced navigational workload, improved tactical situation awareness, and diminished risk of fratricide (destruction of friendly forces).

Instructions to Pilots (Aided Condition)

When the pilot had reached the BP, he was directed to look downward to view the map and its tactical overlay data showing the EA. "As you can see on the map, the EA is divided into three firing sectors. Your team has been assigned the center sector. On my command, you will bob up to an altitude sufficient to view the EA sectors drawn out on the terrain and observe a column of enemy tanks. You are to fire on only two tanks: the one closest to the left boundary of the center sector and the one closest to the right boundary of the center sector. Both shots must be completed within 15 seconds after the bob-up, then bob down to land at the BP."

Overall Response

The pilots were perhaps even more enthusiastic about the EA symbology than the waypoint symbols. Comments included "huge utility," "worth their weight in gold," "enormously easier," "I love that symbol," "awesome," "so much easier," and "tremendous workload reduction."

All of the pilots confirmed the difficulty of the fire control and distribution process. "Units spend a lot of valuable time at the BP trying to get this right." Pilots can't tell where the targets are without good target reference points, and these are rarely available. Currently, in the operational setting, "dicing up the EA is always a challenge." Even though there may be roads and streams in the area, actually seeing them at night "can be quite challenging." The EA symbol would "save time, ordnance, confusion, and money," and avoid the problems of fratricide and "hitting the same target many times." The EA symbol would lead to "a marked increase in the economy of ammunition used." Without these symbols, "it's a stab in the dark." None of the pilots characterized the experimental task as unrealistically difficult.

Information Distribution

Two pilots observed that it's important that both the pilot and the CPG have the EA symbols for situation awareness and coordination. A very experienced pilot stated that the fire control sectors in the EA should be identified during mission planning, using the AMPS, and this information should somehow be directly routed to the HMD symbology generator. The same pilot noted, however, that sometimes when the unit arrives at the BP, the tactical situation has shifted and in such cases it would be extremely valuable for the battalion commander to be able to "data-burst" new fire sectors to the companies. Two pilots suggested that "you should show battalion, company, and fire team sectors," and some suggested the use of color codes for identifying the various sectors.

Use as a Masking Cue

The use of the dashed EA lines as a cue to masking from the enemy positions received mixed reviews. Many found the broken red line masking cue to be very valuable. One pilot, for example, stated that "the use of the dotted lines as you're moving in to get to the BP helps a lot." Another said "I can't believe how much better I flew this" (section of the route) because of the dashed line cue to masking. Some who praised the solid lines nevertheless found the dashed lines "potentially confusing" because of their unfamiliar perspective. The confusion might disappear with more exposure to the dashed line symbol. As one pilot said, "with more experience" he would "learn to use the solid and broken lines more effectively."

Moding Control Suggestions

Pilots offered a number of potential strategies for when the EA symbology should appear. Several felt it should be enabled after the HA or after the Release Point (the point of dispersion of company aircraft after the HA and before the individual BPs).

Some felt that the symbol could come on at some standard range, such as "15 kilometers," "5 kilometers," "3 to 6 kilometers," or "no later than 3 to 4 kilometers." But others said that the range would depend upon the type of terrain in the area and the airspeed.

One of the pilots indicated the EAs should be displayed in accordance with the "weapons and vulnerability" situation, particularly the "maximum effective ranges." For example, "if the BPs put you outside the enemy engagement range, then it would not be necessary to put the EA up sooner than the maximum effective range" of one's own weapons. Thus, if in premission planning, the maximum ADA range was known, "you could use that" (to control EA appearance) "and fly with a little more confidence." using the EA symbol absence as a "safe zone" indicator.

Several pilots stated that they would like to be able to use a manual control or a voice command to call up the EA symbology whenever they wanted it, and just as quickly, to get rid of the symbology and its potential visual clutter.

Slope Landing Symbology Demonstration

Background

Although pilots would always prefer to land on flat terrain, sometimes landing on a slope is unavoidable. The Apache slope landing limits are 10° of roll, 7° nose-up, and 12° nose-down. Unfortunately, no clinometer is provided in the aircraft for determining the steepness of slopes. For example, with a lateral slope, the pilot contacts the slope with the upper wheel, then gently lowers the downhill wheel toward the ground by lowering collective, while attempting to judge whether the limit is about to be exceeded from the trim ball and out-the-window visual cues.

Instructions to Pilots

"Apache pilots know that the slope landing limits for the AH-64 are 10° of roll, 7° nose-up, and 12° nose-down. However, judging the actual slope of terrain is difficult. The next symbol we want to show you is the Slope Landing Aid, or inclinometer. [the pilot was shown an illustration as the symbology function was explained).

When one wheel touches the ground, four tic marks appear in the HMD. The two marks in the center are used with the horizon line to show nose-up and nose-down limits. The two tics toward the right sight show the left and right roll limits.

We'll start by looking at the symbology in an aircraft that has already landed on a fairly steep hillside. If you do a slow pedal turn on the ground you can see how the horizon line changes with respect to the tic marks as the direction of slope changes.

Now try gently picking the aircraft up and landing to see how the symbols change and go on and off. As you lower the collective, you can watch the horizon line and the tick marks to see if the slope is acceptable for a landing."

Overall Response

Five Apache pilots evaluated the Slope Landing Aid, and all agreed that it would be a very useful addition. Additional comments included "I like it," "It's easy to understand," "It would be good for any kind of landing," "very helpful," and "I can work with this easy."

Typical Slope Landings

The pilots stated that it is very hard to tell how steep the slope is, especially at night. As a result, they currently avoid slope landings at night unless they are absolutely required. In addition, at night a landing spot may appear to be flat when in fact it is not. After initial touchdown, there is about 6 inches of compression of the strut, then some expected additional compression of the snow or dirt. Then surprises may happen. Day or night, slight slopes can suddenly become much greater when a wheel slips over a ledge, sinks into a gopher hole, or settles deeper into the snow.

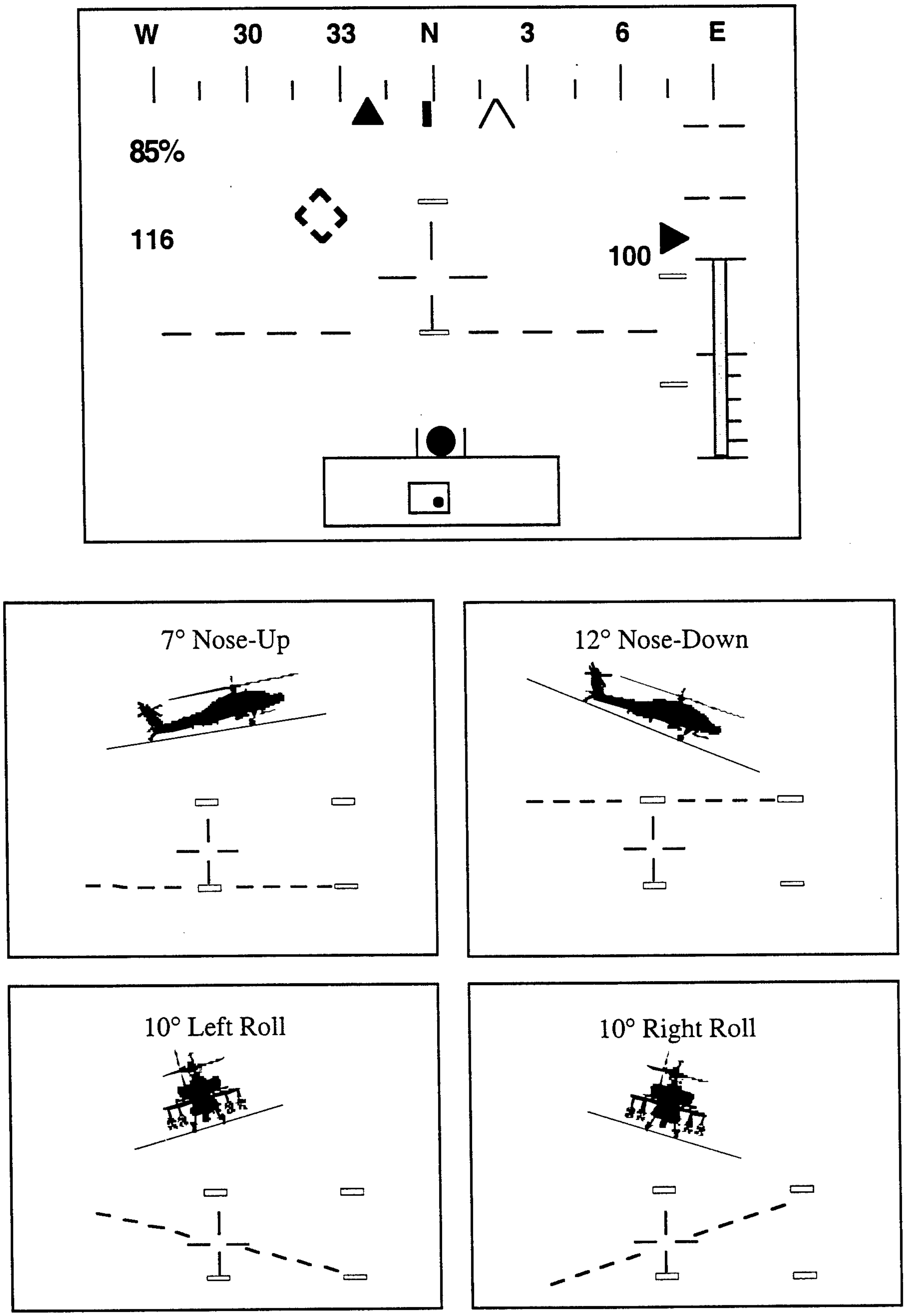


Figure 7-2. The four tic marks used with the horizon line for slope landing.

To counter these surprises, Apache pilots carefully "feel" their way down, to make sure they do not exceed the angular limits of 10° left or right roll, 7° nose-up, and 12° nose down. Currently, their only instrumentation cue for slope landings is the trim ball. The trim ball "rolls" along the top of the field of regard box, and when it reaches the point at which it is centered on the edge of the box, the aircraft is approximately at a 10° roll angle. The ball stops at the edge of the box, so pilots can't actually tell if the 10° roll angle has been exceeded. Of course, the trim ball is not a useful cue for nose-up or nose-down landings, and it's "especially hard to tell for nose-up and nose-down conditions" whether the slope limits are being exceeded.

Moding Control Suggestions

Pilots agreed that the use of the wheel touch-down would be a good way to make the slope landing symbol appear. One noted that "it's good to know that event anyway;" that is, the symbol appearance would be useful in indicating a touchdown. "You can't trust the altitude sensor for indicating your touchdown."

Unfortunately, the Apache "squat switch" is currently implemented only on the left side of the aircraft. This could cause a problem when aircraft on the ground are aligned in "herringbone or wagon-wheel patterns." Two of the pilots suggested that a second squat switch could probably be added at minimal cost. Another approach would be to use an accurate "ground proximity switch." If a ground proximity approach were to be available, "you could simply use the last four feet of altitude" (to turn on the symbol) because below that is the "limit of hovering flight," an Army standard.

Three of the pilots pointed out that in addition to use during slope landings, it was "nice to land and get the horizon line" without having to go back to the transition mode from the hover mode through actuating the thumb switch.

One pilot pointed out that the symbol would not have to be visible whenever the aircraft was on the ground, but would only be needed upon landing, and not at takeoff. So, "if the aircraft systems were turned on while the aircraft was on the ground, the tic marks and horizon line would not be there, but would appear just on landing," an easy rule to implement.

One pilot suggested making the tic marks appear a little bit brighter or a different color than the horizon line for ease of interpretation.

Wind Indicator Cue Symbology Demonstration

Background

The Apache airspeed symbol in the HMD does not currently show the relative direction of the wind, although it does show a speed even if the helicopter is not moving. During Phase I, Apache pilots told us that wind velocity and direction data could be helpful in certain situations such as "cranking or shutting down, takeoff with a tail wind, or descending into trees with a tail wind that might push you into

trouble." In addition, wind data could be valuable for "rocket engagements," "hover taxi," "restricted area landings," "bob-ups," "landing at unfamiliar fields," and "hovering at night in the trees." Head winds and tail winds are the most difficult to detect, since no aircraft attitude changes are available as a cue. Knowledge of wind direction can also be important for aircraft recovery maneuvers, such as after loss of an engine, when flying into the wind may be particularly desirable.

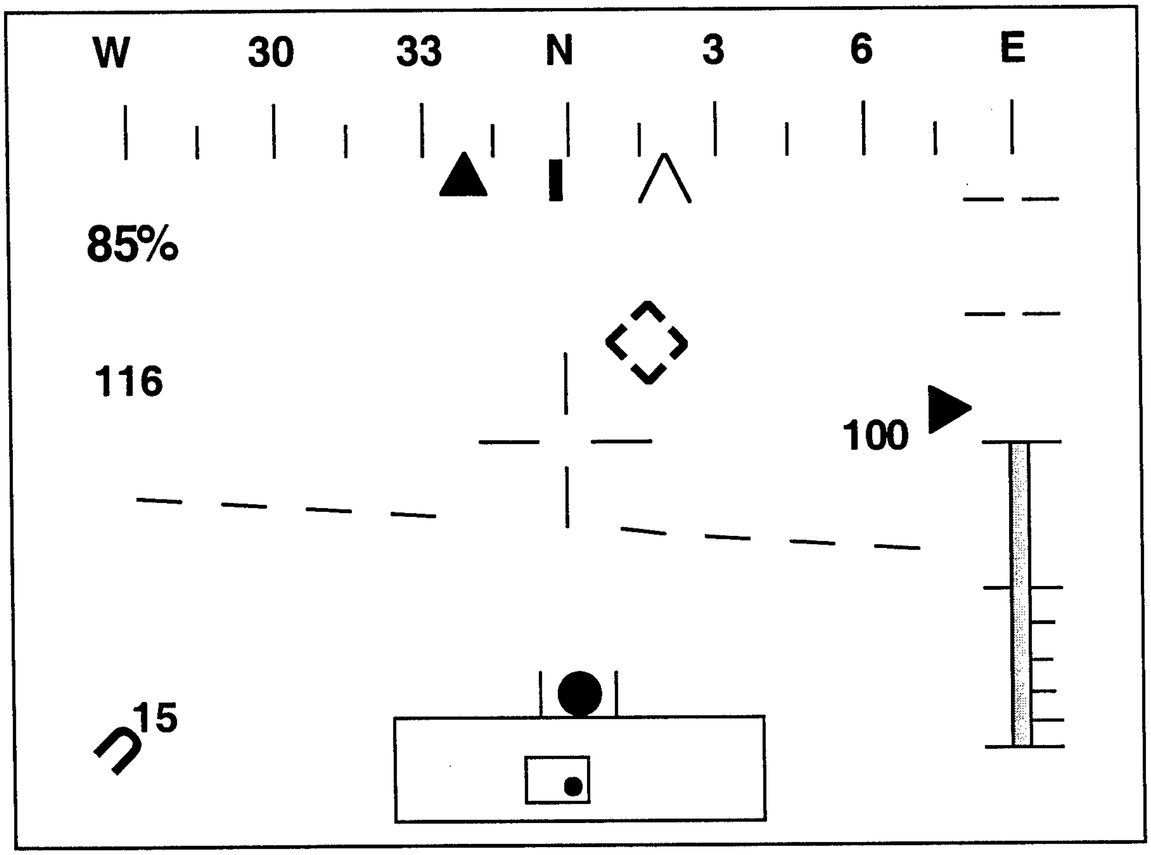


Figure 7-3. The wind indicator cue (lower left).

Instructions to Pilots

"The next symbol we want to show you is a wind indicator. As you know, the Apache true airspeed readout does not show the direction of the wind. although it does show a speed even if the helicopter is not moving over the ground. We've been told that a symbol showing the wind speed and direction relative to the aircraft could be useful (The pilot was shown a figure illustrating the wind symbol).

This symbol, shown in the lower left corner of the display, shows the windspeed numerically. It uses a rounded pointer to show the direction of the wind with respect to the aircraft. This illustration shows how the symbol would indicate a 15 knot wind from about 7 o'clock. (the pilot then donned the helmet).

First, orient the aircraft to the north and do a bob-up maneuver to about 10 feet. (a 15 knot wind from 270° was detected as the aircraft left the ground).

As you see, there is a wind active in the area. Touch down and we'll turn on the wind indicator symbol. Now you can bob-up again knowing which way and how hard the wind is blowing."

Overall Response

All of the five pilots who tried the wind indicator cue found it to be "useful" or "very useful." Other comments included "immediately understandable," "I like it," "would be handy," "would save you time," and "it can only help."

Application with Weapon Engagements

The pilots offered a range of applications for the wind symbol based on their operational requirements. Three of the pilots noted that wind direction "is important for rocket shots." There is a "zero-knot limit for tail winds for firing of rockets, and there's another limit for Hellfire missiles, so this would be useful for weapon engagements." One of the pilots stated that "the rocket ADS ballistic solutions do, in fact, include wind calculations; however they are not shown to the pilot." He also observed that even though it's undesirable, "sometimes you still have to shoot with the wind up your tail." When firing rockets, knowing the winds would also "be handy for using Kentucky windage."

Application in Mountain Operations

Two of the pilots stressed that in mountain operations "it's very important to understand the winds for pinnacle or ridge line operations." These pilots "do a lot of power management work at 6,000'+ altitudes, up to 7500', so winds are critical in hovering and landing." Pilots must be sure to fly into the wind for pinnacle approaches. They currently perform a "high recon," flying a circular pattern around a position to determine the direction and strength of the winds. The wind symbol "would save a lot of workload in determining the best approach," and, "since at airspeeds of greater than 35 knots you don't make such landings, it would be nice to know that figure, as well."

Applications in Other Operational Requirements

The pilots described a number of other situations in which the wind indicator cue would be valuable. "If you're shooting an approach, you want to see if there's a tail wind. It's hard to tell unless you're very experienced." "When you perform health indicator checks for the engines, you must orient the aircraft into the wind." "It would also be useful for roll on landings to unimproved areas. That way you could both put the aircraft into the wind, and by flying into the wind, keep the dust behind you when you land." The symbol would be useful "particularly on cranking or shutting down." "It would also be very useful if you had a single engine out." "You want to land into the wind when you're at the FARP, so it would be useful for that." "It would enhance situation awareness such as hovering at night near trees." "It is also useful for showing which way the dust and snow will blow." "A lot of

times I wish I knew what the windspeed was, especially on take-off from the FARP or the holding area. I currently use dust to figure out which way the wind is blowing."

Symbol Appearance and Placement

None of the pilots took issue with the symbol appearance. For example, one said "This symbol is immediately understandable without any explanation. It appears like a wind sock." All indicated that the symbol location was acceptable although one pilot noted that "you may want to raise it up a bit to make sure it doesn't interfere with the lower-left side of the high action display."

Moding Control Suggestions

Two of the pilots thought that a manual moding technique or a voice command would work best to bring up the symbol or delete it, whenever desired. Looking "down into the cockpit" should definitely not be required to set this mode. Others believed that certain combinations of airspeed, windspeed, wind direction, and altitude should be used to call up the symbol and thereby alert the pilot. One said that "it should be visible when the winds are above 10 knots in any direction." Another pilot suggested that "below 6 knots means wind speed equals light and variable, so perhaps below 6 knots wind speed you would not need to display it." Another stated that it should be "made visible from take-off through 20 knots above effective translational lift."

One of the pilots pointed out that "usually only winds in excess of 30 knots are any kind of problem for the Apache, although a tail wind of 5 knots could be important." Another stated that "you would not need the indicator at higher altitudes enroute and in the cruise mode." Yet another said "you could probably take it off when you're above 5 knots airspeed." The pilots that discussed the use of the symbol in rocket operations pointed out that moding would be easy; "whenever you use the WAS switch to select rockets, you should get the wind symbol coming up."

Speed-to-Fly Symbology Demonstration

Background

Accuracy in arrival times at certain waypoints or other tactical positions can be critical to mission success and aircraft survival. For example, inbound and outbound Passage Point arrival times must be very accurate (± 30 seconds accuracy is allowable) to avoid risking "friendly fire." The existing airspeed display is, by definition, influenced by winds and does not provide ground speed unless the pilot "fails" the ADS. As an alternative, the CPG can be further burdened with a request to repeatedly calculate GS and tell the pilot to "speed up or slow down a little." Given the current speed, the Doppler system alone can be used to determine the ETA at a waypoint. However, the system does not "know" whether the aircraft is on time, or by how much it is ahead or behind schedule. Some kind of cue to determining

correct time of arrival could be a significant workload reducer for both the pilot and the CPG.

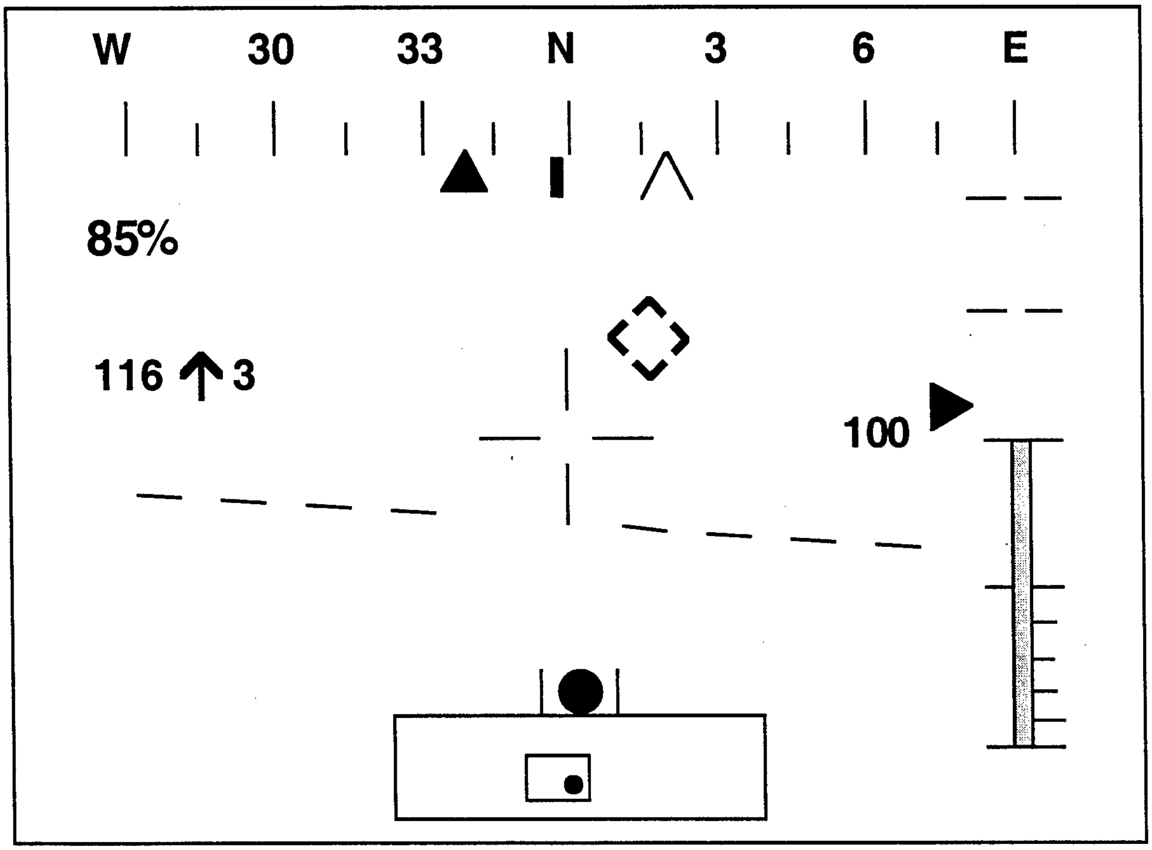


Figure 7-4. The speed-to-fly cue next to the 116 knot airspeed symbol.

Instructions to Pilots

"The next new symbol we want to show you is called the Speed-to-Fly Cue. Pilots have told us that hitting certain waypoints on time can be important, such as at passage points. The Doppler system can calculate ground speed and ETA at a waypoint, but does not 'know' if the aircraft is ahead or behind schedule.

We can compare the ETA with the required waypoint time and display a symbol that looks like this next to the regular airspeed indicator (the pilot was shown an illustration).

The 'up' or 'down' direction of the little arrow next to the airspeed tells the pilot whether to increase or decrease airspeed, and the number to the right how much to change it for accurate arrival time at the next waypoint. We'll begin near Waypoint 1 and fly to the HA."

Overall Response

All of the five pilots that tried this symbol found it to be very useful. Other comments included "definitely a useful addition," "much faster," "more accurate,"

"could relate to time easily," "would reduce workload," and "its location and appearance are just perfect."

Improvement Over Current Operations

The specific waypoint times derive from the planning process. "You back-plan from the FLOT time or other critical position, and then set the times for each point, given the ground speed and the distance." Pilots usually "fudge for the winds," and do a Doppler check along the way. Enroute, the pilot "can turn the ADS (air data sensor) off and get the ground speed. But most pilots prefer to leave the ADS on for use with waypoints.

The pilots were adamant regarding the necessity of accurate waypoint arrival times. One said that "Timing is really important, especially in and out of the passage point, the cross FLOT times must be within plus or minus 30 seconds. It's critical." Another stated that waypoint times are "nearly always important, but are critical with SEAD (suppression of enemy air defense) missions when there are artillery barrage times" to be considered. "To be either early or late over these points is dangerous."

For accurate data, the pilot has to ask the CPG for time-distance information. The CPG must use the Doppler (which provides ground speed in knots) and do "a lot of calculations." He determines the necessary true airspeed for the aircraft to deliver the proper ground speed for each leg, then relays the information to the pilot, suggesting that he increase or decrease current airspeed to make the waypoint time.

The pilots noted that with the speed-to-fly symbol, all this calculation and communication would be unnecessary. "It would also prevent a lot of speed fluctuations between waypoints." Every one of the pilots considered the speed-to-fly cue to be a very useful addition.

One pilot observed that it would be possible to use the speed-to-fly cue as an indicant of "when to transition to the start point on the egress route." For example, if the crew had 15 minutes station time plus 2 minutes to get to the start point, "in your setup you could enter 17 minutes to the start point from the BP arrival time." Then "you would just wait until the display says it's time to leave." That is, the symbol would appear with an up arrow and a speed increase (such as "80 knots"). Or, if the aircraft left the BP late for some reason, "it would give you the needed speed to make that start point at the egress route."

All agreed that the location and its format are just fine as they are. One pilot suggested color coding the number or putting the number above or below the airspeed to show the direction of change so that the arrow would be unnecessary and some clutter could be saved.

Moding Control Suggestions

One of the pilots thought "it would be great to have on continuously," and another recommended a manual on-and-off switch for cases in which they don't require this information during flight. "The switch could be on the cyclic or a voice command could be used."

One pilot suggested that the display of the speed-to-fly cue "could start at a 40-knot airspeed or perhaps 20." The important concept is to recognize when the aircraft is actually flying, not hovering. For example, "we're doing 120 knots at the release points." When the aircraft is hovering and "moving short distances such as around the BP," the speed-to-fly cue would "not be much help." Another agreed that "it could probably be decluttered in some NOE mode" since "100-120 knots is a typical enroute ground speed, and the passage points are generally overflown at 50 feet."

Pilots were also asked how great an error from the ideal flight airspeed should trigger the appearance of the arrow and number. The demonstration used a 1 knot difference. Several pilots agreed that 1 knot was appropriate, although one pilot suggested a 5-knot error as the cue for the symbol to appear. Another insightfully suggested that during the use of "your mission planning software, you could determine the different boundaries for when the cue would appear, perhaps down to 1 knot differences when you are close to the BP," or some other critical position.

ASE Threat Cue Symbology Demonstration

Background

Although the APR-39 radar warning device in the AH-64A provides voice warnings of threat activity and their relative direction, such as "Searching - 2 o'clock," Apache pilots interviewed during Phase I had indicated that HMD symbology might provide a better situation awareness cue. In order to permit rapid masking of the aircraft, instead of receiving just a numerical bearing to the threat, it was suggested that the HMD present an enemy weapon symbol in the field of regard, perhaps supplemented with a 3-D audio cue, to more naturalistically represent the weapon's position in space.

Since the APR-39 does not provide distance-to-weapon information, the symbol could not be used to identify a specific position on the ground, but would have to show the azimuth to the weapon. Pilots have indicated that the HMD symbology could give a spatially superior indicant of direction with a line or some other marker so that the pilot could either orient the aircraft appropriately for use of the gun, jammer, chaff, or flares, or prepare to deploy to cover. Unlike a spoken warning, a visible line provides a continuous indicant of the direction of the threat, even as the pilot changes his heading to respond to the threat.

Instructions to Pilots

"The next symbol is an improvement for the APR-39. In addition to the voice warning of the rough direction of threat activity, an ASE Threat Cue Symbol could be presented in the HMD, to point out the direction of the threat. The symbol we will show you is a pair of vertical lines. The target will be found between them. This symbol is used if no good target range data is available.

[A figure depicting the symbol was shown to the pilots] Let's fly through part of the waypoints from the first experiment and see how the ASE Threat Cue Symbol would point out the threat positions. A 3D sound cue will help to indicate the direction of the threat. Fire on the targets then continue route at low altitude."

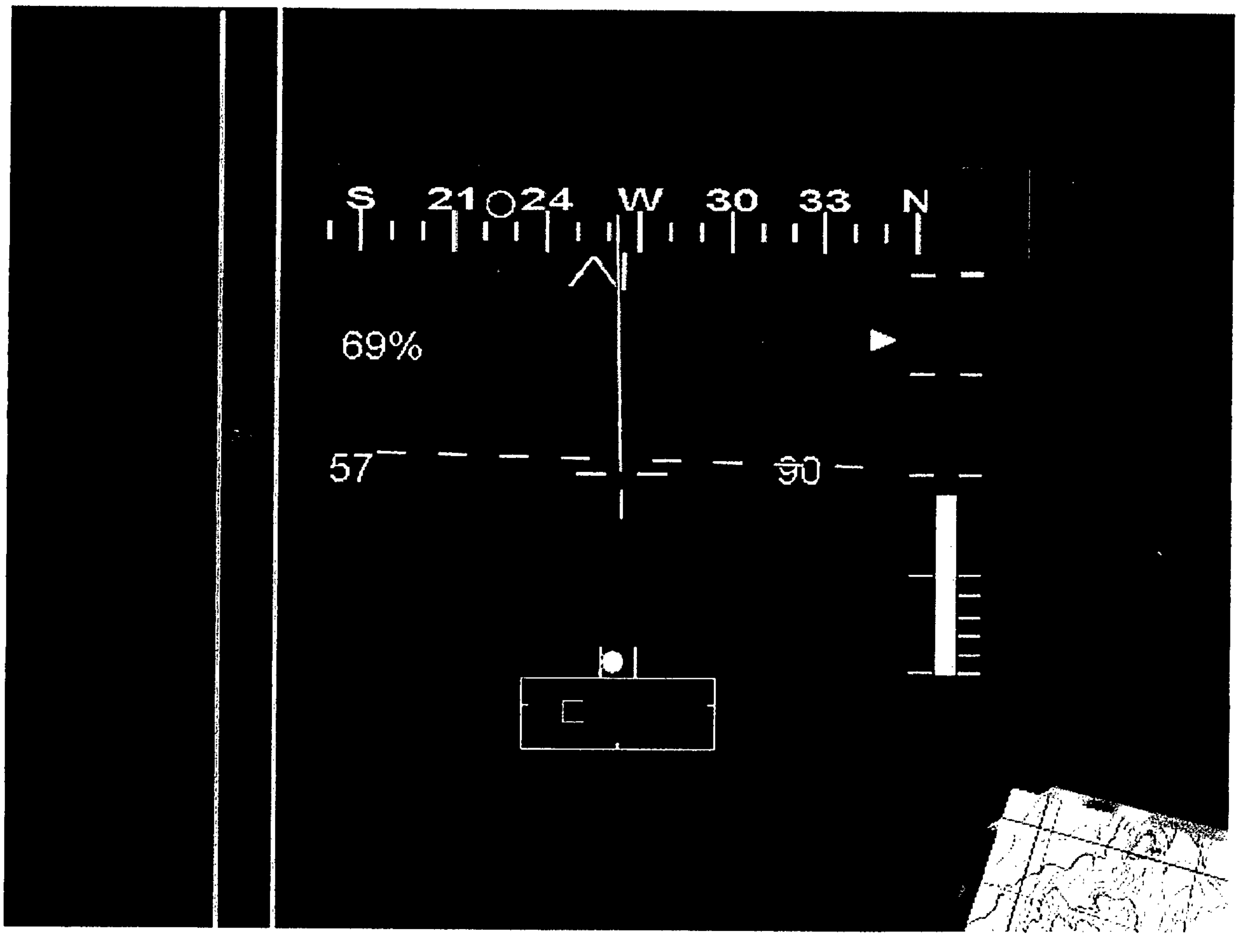


Figure 7-5. The ASE Threat Cue Symbol indicating a target azimuth.

Overall Response

All five of the pilots who tried the ASE Threat Cue symbol were very favorably impressed. Comment included "I like it a lot," "this would be great," "pretty neat," "absolutely a useful addition," "this is a novel, good thought," and "it sure beats looking down at that stupid thing" (the APR-39). It is noteworthy that during their previous two flights through the same area these five pilots detected and fired upon

an average of 1.2 targets per flight. With the ASE Threat Cue symbol, of course, all four of the targets were easily found.

Improvement Over Current Operations

The current APR-39 gives a verbal message such as "ZSU 11 o-clock tracking" and presents "a quick strobe on the head-down display." But "the strobe disappears right away and you may miss it entirely." The pilot doesn't always see the APR-39 strobe line and "a clock position is useless if you're maneuvering too late to figure out the real direction of the strobe." In addition, "this information must be relayed from the pilot to the front seater." The front seater "has to ask the back seat where the strobes are coming from so that he can effectively slew the weapons." Alternatively, "he can slew his TADS line of sight to the helmet line of sight," but using the new ASE Threat Cue symbol is much faster, assuming both the front and the back seat have it. One pilot said that "using it for air-to-air would be great, too."

Use of 3D Sound

The 3D sound is "great' because it "tells you where to look immediately." Otherwise, "it's hard to figure out with the current APR-39." Some pilots felt that a simple buzzer sound such as used in the demonstration would be adequate because "knowing it's there is more important than getting an idea of the specific threat." Two pilots thought the buzzer sounded too much like "an engine-out warning."

Other pilots pointed out that the current APR 39 uses a voice message to indicate the type of weapon of the threat and that the type of weapon is still important information, suggesting that the auditory portion of the cue should perhaps use the name of the weapon instead of a simple tone. "A woman's voice would be okay." The other words of the APR-39 message, such as "tracking, acquisition, launch, or lock broken," should also be included, but done in 3D sound.

Two pilots suggested that a "sound-off button" or a voice command to shut up the warning noise would be good, until another new one came on. "You might need some kind of back-up, such as a 4-minute reminder, so that the warning would come back on if you'd been ignoring it."

One pilot warned that there is a problem to consider in using the 3D auditor warnings for pilots. "Pilots have a lot of time around turbine engines and many have had hearing problems." Thus, especially with lots of noise, "localization is a problem and you can't always depend on that as a cue." Redundant cues such as a pointer or compass heading information to the threat might be useful for crew coordination.

Symbol Appearance

Most of the pilots indicated that the symbol appearance was "good," or "appropriate," and were not particularly concerned about the clutter the two lines would add at this point in the mission. As one of the pilots put it,. "Don't worry

about having two lines--clutter is not a big issue in this case. When the target comes up, it's the most important thing." Two of the pilots liked the two-line approach, but suggested that they be in a color unlike that of the other symbology or the target itself.

Target Prioritization

Several of the pilots suggested some form of additional information be added, for example, something akin to that currently used with the voice warnings of the APR-39. One pilot suggested that it might be good to prioritize pairs of lines for multiple targets by using shape codes for our lines. "You might want to be able to discriminate between tracking or lock or launch so that the first priority would be launch, the second lock, the third tracking, with some kind of shape code." he suggested dotted lines for tracking and solid for acquisition, "or color codes if they are possible." He also noted that the APR-39 currently shows small symbols indicating the type of enemy weapon, so these could be considered for the head-up application as well.

One pilot observed that friendlies might be in the area and "you should use IFF codes to provide blue symbols for the friendlies for fratricide prevention versus red for the opposing forces." There was also some questions regarding the best way to show multiple enemy weapons. It might be possible to draw lines part way down from the top or part way up from the bottom to show secondary priority targets, although either way could begin to introduce clutter.

Moding Control Suggestions.

Pilots agreed that the events that would be detected to make the symbol come on would be the same kind of sensor events that the APR-39 currently uses.

Flight Path Marker Symbology Demonstration

Background

The flight path marker symbol shows the continuously computed velocity vector of the aircraft. The IHADSS symbology, of course, includes a velocity vector that is a "top-down" view useful for hover control. The flight path marker symbol, however, is an "out-the-window" view along the axis of the velocity vector, showing where the aircraft will fly or contact the ground if no changes are made to the controls. Thus, the most obvious virtue of the flight path marker symbol is for avoidance of controlled flight into terrain (CFIT) accidents. The knowledge of the aircraft's velocity vector can be useful in many other ways as well, including terrain following, turn coordination, and precision landings. Although the flight path marker symbol was not derived from our information requirements analyses, its experimental use during PRISMS NOE flights through rugged terrain made its virtues so dramatically evident that we chose to include it in the demonstration sessions.

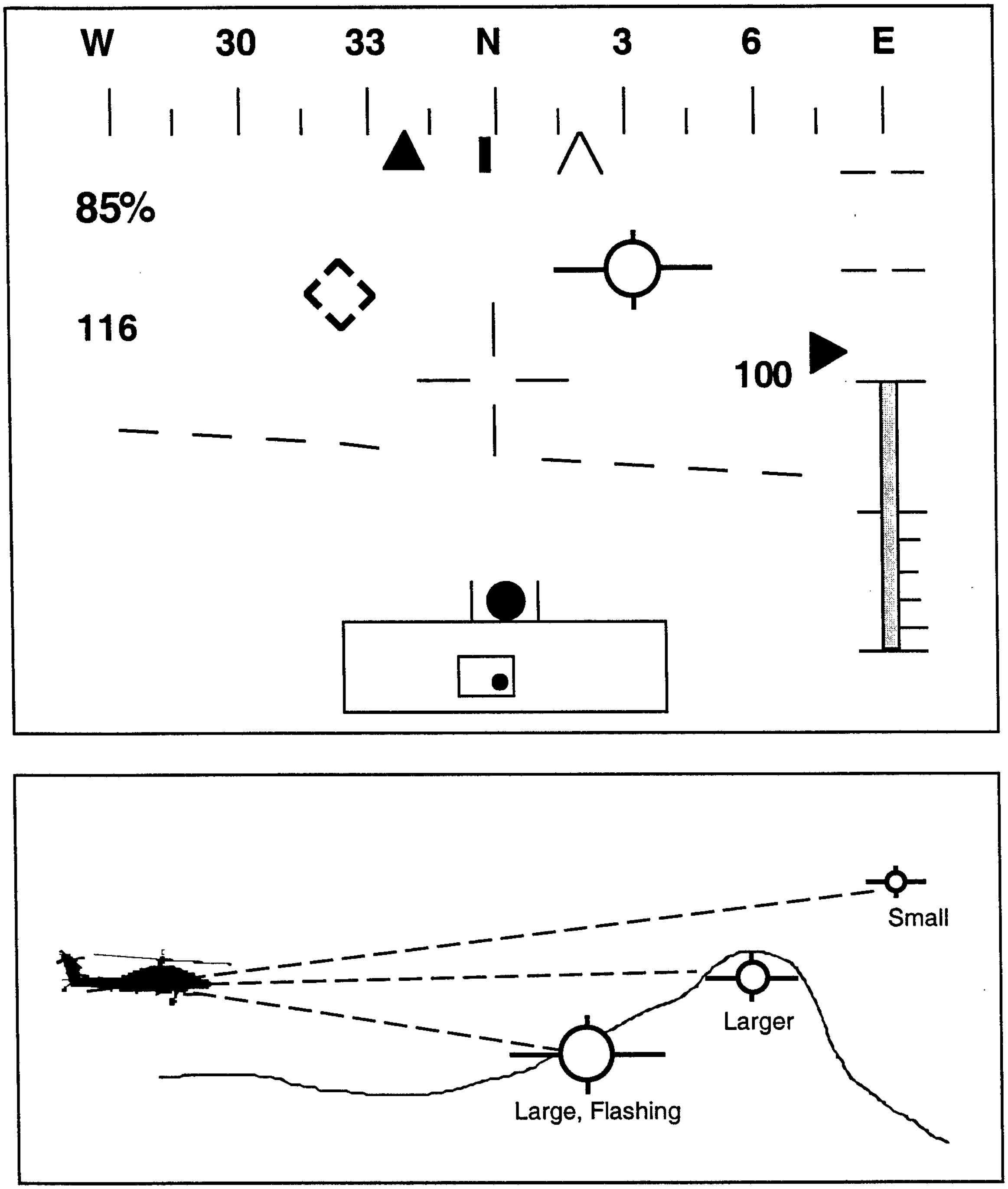


Figure 7-6. Appearance of the flight path marker with the other HMD symbols (upper) and example of the flight path marker changing size (lower).

Instructions to Pilots

"The next symbol we want to show you is called the Flight Path Marker. It shows the continuously computed velocity vector of the aircraft. You can use it to see exactly where the aircraft will fly or contact the ground if control inputs do not change. We have it set

up so that the symbol "grows" in size as the impact point becomes nearer to the aircraft, and will begin flashing at 3 seconds to impact.

First, let's compare landing at a specific position without and with the Flight Path Marker. From about 500 feet, land at the pad. Next, we'll try it with the Flight Path Marker on. Just keep the Flight Path Marker positioned on your desired landing point.

(Later, after landing exercises)

Now let's try it out first flying low and fast. Observe how it moves with your control inputs and how it changes size. See if you can get the flashing warning of 3 seconds to ground impact."

Overall Response

All of the five pilots who evaluated the flight path marker symbol were strongly in favor of its addition to the symbol set. Comments included "a really good addition," "it would be great," "very useful," "excellent," "pretty nice," "it's a good tool," "especially useful at night," "a precise power manager," and "it could save your life."

Utility in Tactical Flight

All of the pilots agreed that "this would be a really good addition for low-level flight," especially in for terrain following and terrain avoidance." Accurately clearing ridgelines without "ballooning to 400 feet" is another requirement that would be aided by the flight path marker. One pilot observed that "it's good for night flight, especially, because it's hard to see the terrain then." Another pilot tried it with aggressive turns and pronounced it "great for sharp turns while you're losing altitude."

Utility for Landings

Pilots also agreed that "it's good for setting up landings," because it's not necessary to "look inside the cockpit for information" during the landing. One stated that it was "great for shooting approaches" because the pilot doesn't "have to check several different things." Another said "I like it. Especially for roll on landings." It provides a "good rate of descent cue," and the landing position can be fine-tuned, using the symbol as a "precise power manager," keeping the symbol over the intended landing spot. It would also be useful for autorotations, setting the aircraft attitude to produce an 80-knot airspeed and putting the symbol on a desired landing area.

Utility with Weapons

One pilot was particularly interested in the use of the flight path marker with rocket fire, suggesting that the symbol might indicate "both the aircraft's and the rocket's point of impact in the terrain." when using direct fire methods. Another pilot noted that the symbol would be valuable in "determining the pull-up point for diving fire" with the gun or rockets.

Utility in Flight Instruction

An instructor-pilot indicated that as a safety cue, flashing the flight path marker symbol would "be excellent for flight with students. At low level, high speed, you really need to detect descent in a hurry." He and another pilot suggested that an auditory warning message such as "Pull up" be added to correspond with the flashing flight path marker.

Symbol Implementation

Pilots were very much in favor of the flashing symbol indicating imminent ground impact, one saying "it could be what saves you," and another saying "it will help you survive in flight." However, there was some disagreement over the warning period. The demonstration used a three-second warning, but three of the pilots suggested that 5 seconds might provide a greater margin of safety. The size-changing feature was judged to "get your attention well." One pilot suggested that in addition to flashing, perhaps it "ought to change to red." Another suggested that it be made to look more different from the acceleration cue, to avoid any confusion.

Moding Control Suggestions

One of the pilots suggested that the flight path marker be continuously displayed for safety purposes and as a training aid for improving landing technique. Four of the pilots stated that it could be intelligently moded in accordance with altitude and airspeed. One said that "it should be on at all times when less than 500 feet AGL." Another said "above 200 feet you would not need this symbol," and yet another said it should appear at "less than 100 feet." One suggestion was that the flight path marker "would be unnecessary in hover or bob-up modes," and could be turned off in those cases, but should come back on when airspeed reached "30 to 40 knots." Another pilot said that the symbol should be shown for NOE flight, or "anytime below 80 knots and below 100 feet."

One of the pilots described the NOE approach switch setting, and its effect on the flight path marker. This switch "schedules" (moves) the stabilator so that the aircraft nose comes down for better visibility. That is, it "moves the nose down without moving the rotor disk." Thus, if this switch were actuated, "you might not want to display the flight path marker," or at least a correction to the symbol locations should be studied.

Survey of Symbol Usefulness

Although a large number of potential HMD symbols had been identified in our analyses (as described in Section 4), only a few examples of various symbol types could be evaluated with the PRISMS simulator in the time available with the Apache SMEs. In fact, the PRISMS simulator was developed for years of future use based on recognition of the overwhelming number of demonstrations, evaluations, and experiments that should be undertaken in specifying the content and characteristics of new HMD symbology.

Development of the Survey Tool

Having identified so many potential symbols, we were anxious to prioritize them in terms of their probable payoff for Army pilots. Having just completed a series of symbol evaluations on the PRISMS simulator, it seemed that the pilots would be ideally prepared for judging the utility of other new symbols. Thus, a survey and rating scale approach appeared to be the most appropriate method for creating such a prioritization. Unfortunately, the number of information elements in our full list would have resulted in a survey that would have been quite long and tedious for the pilots. Another problem with attempting such ratings was that many of the new symbols would be difficult to understand without a detailed explanation, further increasing the demands of a survey task beyond acceptable limits.

In order to reduce the severity of both problems, we elected to review our list of potential symbols and reduce their numbers by selecting only those that would easily be understood by experienced pilots without special explanations. As a result, the final list of survey items consisted of 85 information elements. The survey was presented to the pilots after they had completed 90 minutes of PRISMS symbology evaluations with a request that they complete and return it to Anacapa Sciences as soon as possible. The survey instructions were as follows:

> Please consider your answers to the following questions carefully. Your responses will help to guide the next generation of HMD symbology. All aviators' answers will be kept strictly confidential by Anacapa Sciences.
>
> During the demonstrations in the PRISMS simulator, you saw several new kinds of HMD symbols. Having had this introduction, you can more easily imagine how other new symbols can be created. Some might be words or numbers, and others might be "earth-fixed" and point out positions or areas in the real world, like the waypoint markers and EA boundaries. If the right rules can be developed, these new symbols could be made to appear when needed, then disappear so as not to clutter the pilot's view.
>
> Listed below are a series of information elements that have been suggested for presentation as symbols on the HMD. Please rate their usefulness as an HMD symbol, assuming that the information element was presented only when needed.

A 7-point rating scale was used in which "1" was equivalent to "Not useful," and "7" was equivalent to "Very useful," as shown in the sample below:

Information Element	(Circle the appropriate number) Not Useful ... Very Useful
1. Wind direction relative to the aircraft	1....2....3....4....5....6....7

As a further confirmation of the most critical new symbols, once the SMEs had finished the ratings they were instructed to look back through their ratings and identify the 20 most important symbols. They were further instructed that "You may have to make some additional decisions about which ones are most important if some are tied at the same rating number."

Results of the Survey

Six of the study participants completed the entire survey form and returned it to us. The results are based upon these six sets of ratings and are shown in Table 7.1 rank-ordered by importance of the information element. The number to the left of the information element is its position in the list of 85 symbols. The number to the right of the information element is the mean rating score.

Table 7.1
Information Elements Ranked by Usefulness

74.	Airspace zones: threat lethality envelopes	6.67
79.	Enemy forces locations	6.67
12.	Distance remaining to next waypoint	6.50
44.	ASE warning: threat weapon status	6.50
47.	Ground positions: engagement areas, fire sectors	6.50
48.	Ground positions: next waypoint	6.33
54.	Ground positions: battle positions	6.33
58.	Ground positions: FARPs	6.33
60.	Ground positions: friendly troops	6.33
42.	ASE warning: head-up direction cue to threat	6.17
43.	ASE warning: head-up position cue to threat	6.17
50.	Ground positions: passage points	6.17
51.	Ground positions: air control points	6.17
52.	Ground positions: rally points	6.17
53.	Ground positions: holding areas, assembly areas	6.17
61.	Ground positions: friendly artillery	6.17
7.	Ground speed required for on-time arrival at waypoint	6.00
9.	Time remaining for on-time arrival at waypoint	5.83
49.	Ground positions: any selected waypoint	5.83
56.	Ground positions: no-fire zones (NFA)	5.83
59.	Ground positions: phase line and force boundaries	5.83
68.	Airspace positions: flight team members	5.83
1.	Wind direction relative to the aircraft	5.67
62.	Airspace positions: air targets	5.67
81.	Forward Line of Own Troops (FLOT)	5.67
83.	Landing Zones (LZ)	5.67
10.	Time remaining for on-time arrival at destination	5.50
57.	Ground positions: fire support coordination lines	5.50
82.	Hazards to flight	5.40
3.	Current ground speed (knots)	5.33

Table 7.1. Continued
Information Elements Ranked by Usefulness

8.	Airspeed required for on-time arrival at waypoint	5.33
67.	Airspace positions: air targets detected by sensor	5.33
80.	Forward Edge of the Battle Area (FEBA)	5.33
2.	Wind speed relative to the aircraft	5.17
35.	Flight path marker (as shown in PRISMS)	5.17
45.	Time of guided missile flight for LOAL	5.17
46.	Time to designate target for LOAL	5.17
55.	Ground positions: free-fire areas (FFA)	5.17
33.	Bearing pointer to ADF or VOR	5.00
76.	Speed-to-fly cue, like shown with PRISMS	5.00
84.	Fire support: Restrictive Fire Line (RFL)	5.00
63.	Airspace positions: next to shoot target	4.83
17.	Autorotation flare timing and pitch cue	4.67
36.	Numeric heading indicator	4.67
11.	Mission time clock	4.50
15.	Roll-on landing warning: parking brake on	4.50
16.	Roll-on landing warning: tail wheel unlocked	4.50
65.	Airspace positions: restricted areas	4.50
77.	Slope landing aid, like shown with PRISMS	4.50
73.	Airspace zones: NBC contamination	4.40
30.	Distance and direction to planned track	4.33
69.	Airspace zones: air routes and corridors	4.33
85.	Coordinated Fire Line (CFL)	4.33
37.	Synthetic canopy rails for night pilotage	4.25
4.	Current ground speed (kilometers/hour)	4.17
5.	Planned ground speed (knots)	4.17
32.	Course deviation bar	4.17
20.	Alert: Fire or other caution or warning	4.00
21.	Radio frequency numerics (when setting)	4.00
22.	Transponder numerics (when setting)	4.00
31.	Current ground track	4.00
6.	Planned ground speed (kilometers/hour)	3.83
38.	Minimum single engine airspeed	3.83
70.	Airspace zones: approach holding patterns	3.83
18.	Alert: Minimum enroute altitude	3.67
19.	Alert: Minimum obstruction clearance altitude	3.67
66.	Airspace positions: rendezvous aircraft	3.67
71.	Airspace zones: approach path	3.67
72.	Airspace zones: missed approach path	3.67
78.	Control setting warning: (e.g., DASE off)	3.67
75.	Training cues like shown with PRISMS pirouette	3.60
13.	Current barometric altitude (MSL)	3.50
28.	Fuel remaining (time at present burn rate)	3.50

Table 7.1. Continued
Information Elements Ranked by Usefulness

34.	True course	3.50
14.	Planned barometric altitude (MSL)	3.33
24.	Pitch angle scale (ladder)	3.33
41.	Obstacle avoidance distance cues	3.20
39.	Time until damage from high torque condition	3.17
25.	Roll angle scale	3.00
26.	Engine temperature	3.00
27.	Fuel remaining (pounds)	3.00
40.	Obstacle avoidance directional cues	3.00
23.	Radio call sign	2.67
29.	Rotor speed indicator	2.67
64.	Airspace positions: refueling tanker	1.50

The results of the second task, identifying the twenty most important information elements was included to supplement the 7-point scaling method in case the ratings were concentrated in one sector of the scale. The results of this method are shown in Table 7.2. It is interesting to note that, in general, there was good correspondence between the rating scale method and the top-twenty method. Furthermore, there was quite good agreement among pilots with regard to the top twenty; all pilots agreed that the most important information element was "Enemy forces locations," and at least half of the respondents agreed on the top twenty items.

The importance of symbols indicating tactical ground positions is powerfully confirmed by both survey approaches. In the rating scale technique, 15 out of the most important 21 features were ground positions (including enemy forces locations, and in the top-twenty method, 9 of the 20 most important symbols identified ground positions.

It is noteworthy that of the 20 most important symbols, 10 had been previously selected for use in our PRISMS experiments and demonstrations. Although it is possible that a case could be made for the PRISMS sessions having influenced subsequent ratings, we believe that this finding simply reflects the accuracy of our estimates of high-payoff symbols based upon the Phase I tasks as well as many years of experience in analysis of Army aviation mission requirements.

In any case, the survey data presented in this section should provide valuable guidance for HMD symbology research in the near future. Although the information content for each symbol has been identified, each symbol's format and behavior must be determined through further demonstrations and evaluations. It is our hope that the PRISMS simulator will play a key role in the performance of this research for years to come.

Table 7.2.
The Twenty Most Important Information Elements as Reported by the Survey Respondents (percentage of respondents shown at left).

100%	79.	Enemy forces locations
67%	7.	Ground speed required for on-time arrival at waypoint
67%	8.	Airspeed required for on-time arrival at waypoint
67%	42.	ASE warning: head-up direction cue to threat
67%	44.	ASE warning: threat weapon status
67%	48.	Ground positions: next waypoint
67%	50.	Ground positions: passage points
67%	51.	Ground positions: air control points
67%	54.	Ground positions: battle positions
67%	58.	Ground positions: FARPs
67%	60.	Ground positions: friendly troops
67%	74.	Airspace zones: threat lethality envelopes
50%	1.	Wind direction relative to the aircraft
50%	9.	Time remaining for on-time arrival at waypoint
50%	12.	Distance remaining to next waypoint
50%	35.	Flight path marker (as shown in PRISMS)
50%	43.	ASE warning: head-up position cue to threat
50%	47.	Ground positions: engagement areas, fire sectors
50%	49.	Ground positions: any selected waypoint
50%	67.	Airspace positions: air targets detected by sensor

Session 8: References

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